The SEMATECH high-NA actinic reticle review project, an EUV mask-imaging microscope

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BERKELEY LAB
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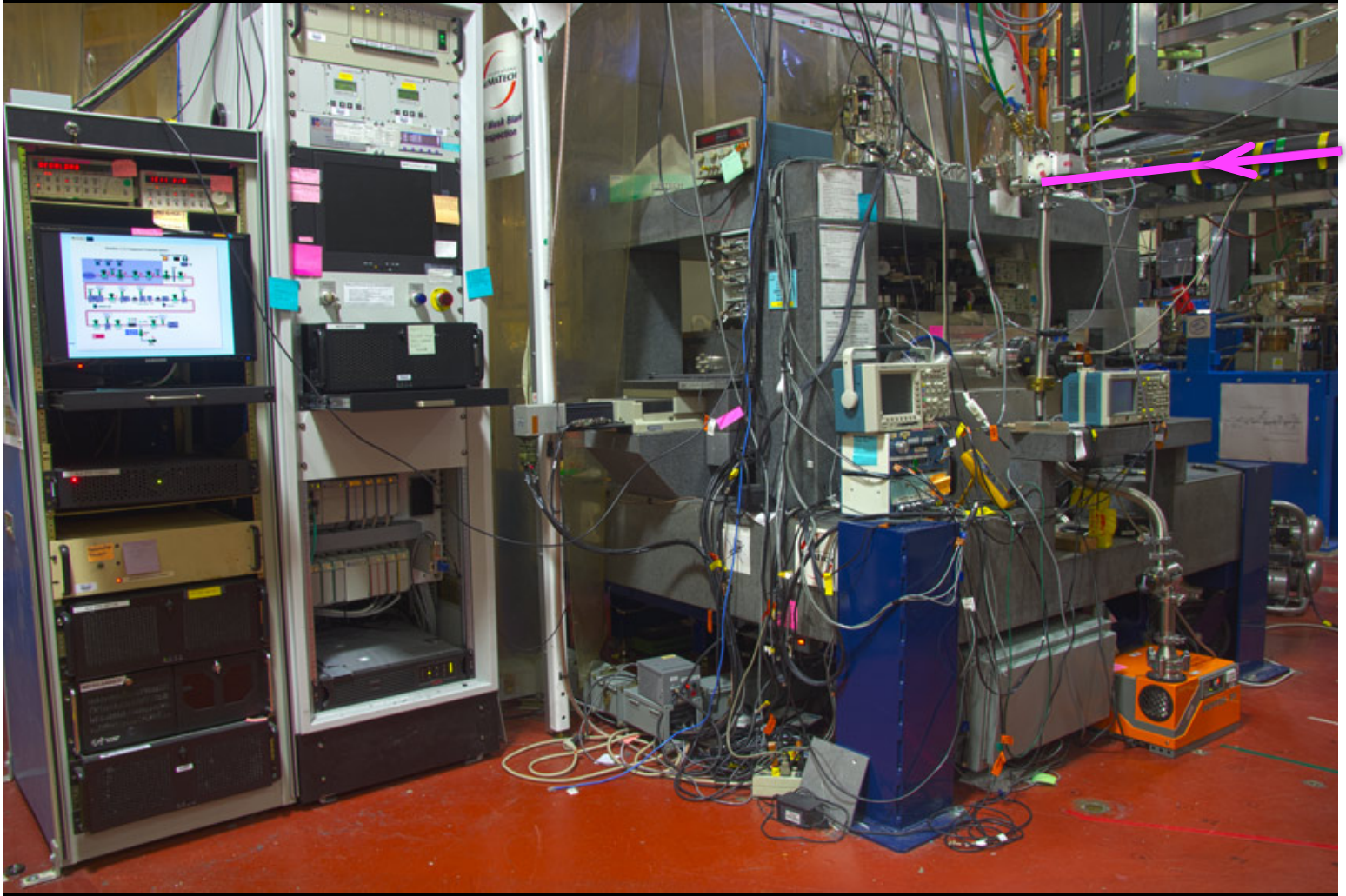
SHARP
SEMATECH HIGH-NA ACTINIC RETICLE REVIEW PROJECT

SEMATECH



AIT: 2004–2012 *Retired*

Source: Synchrotron

Optics: Zoneplate-lenses

4×NA: 0.25–0.625

σ: Programmable

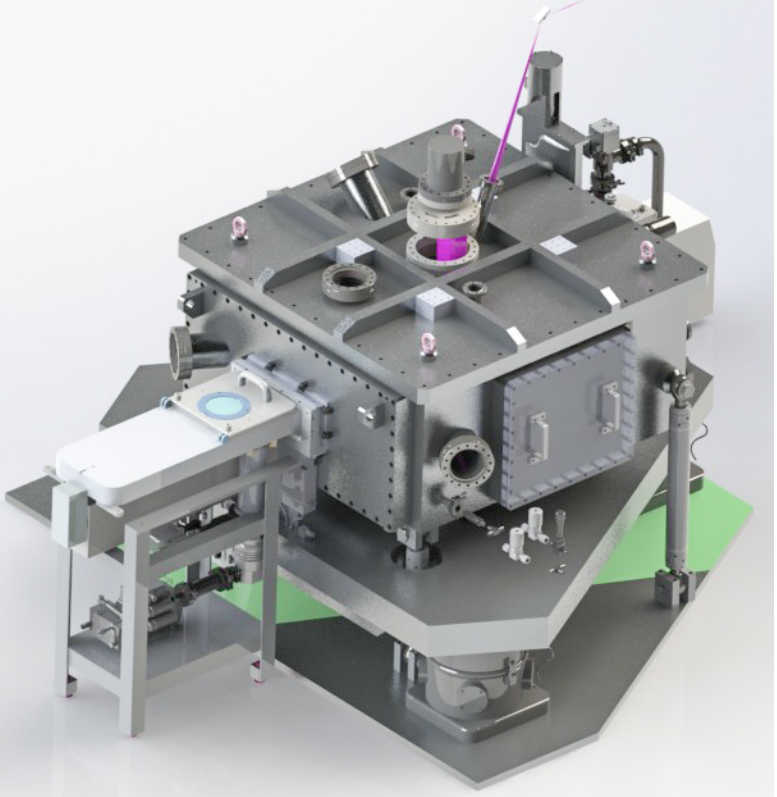
Nav: Full-mask *xy*

Speed: 5–10 series/hr

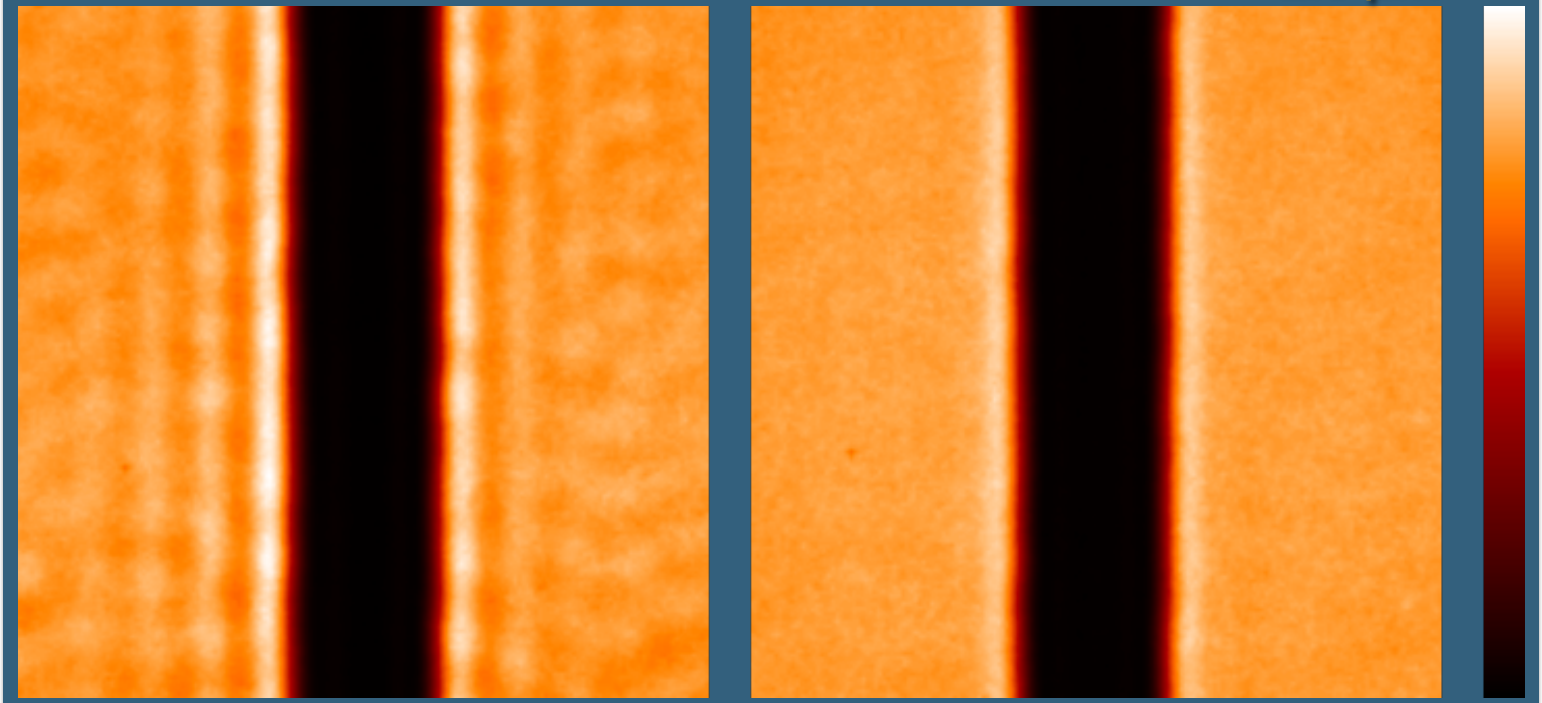
Vibration Isolation

SHARP

SEMATECH HIGH-NA ACTINIC RETICLE REVIEW PROJECT



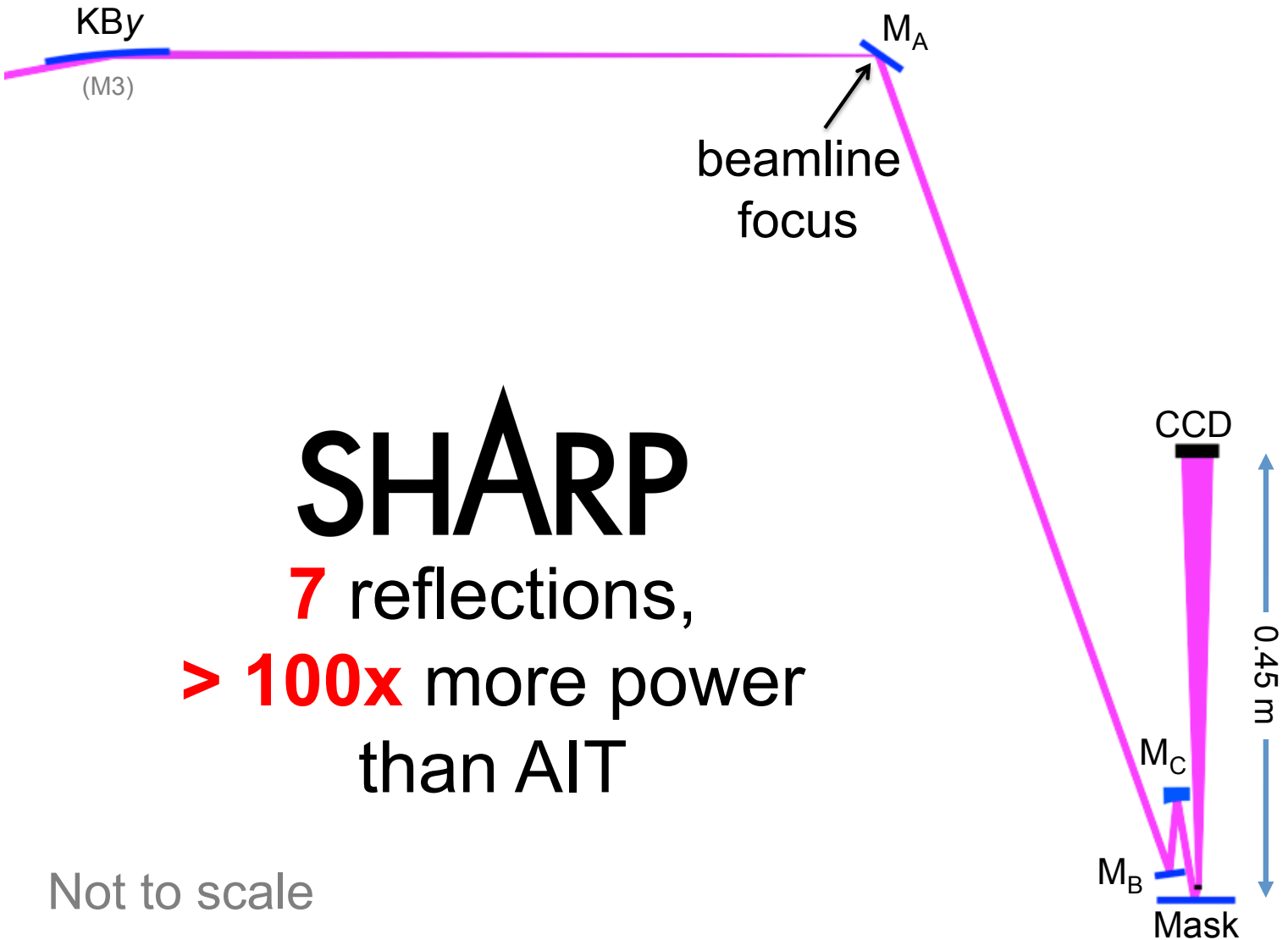
Coherence control is important



coherent
σ ≈ 0

partially coherent
σ = 0.5

SHARP

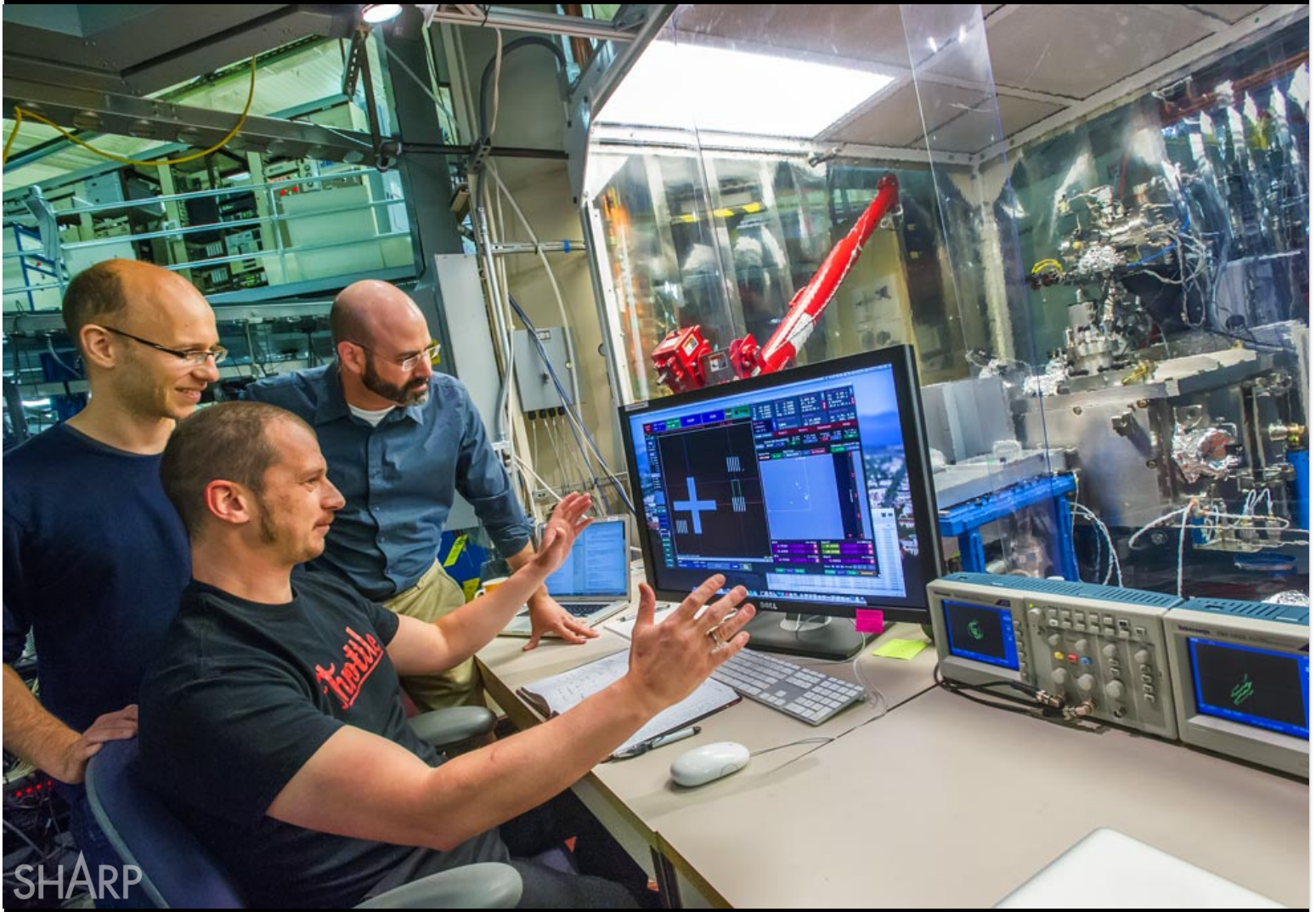


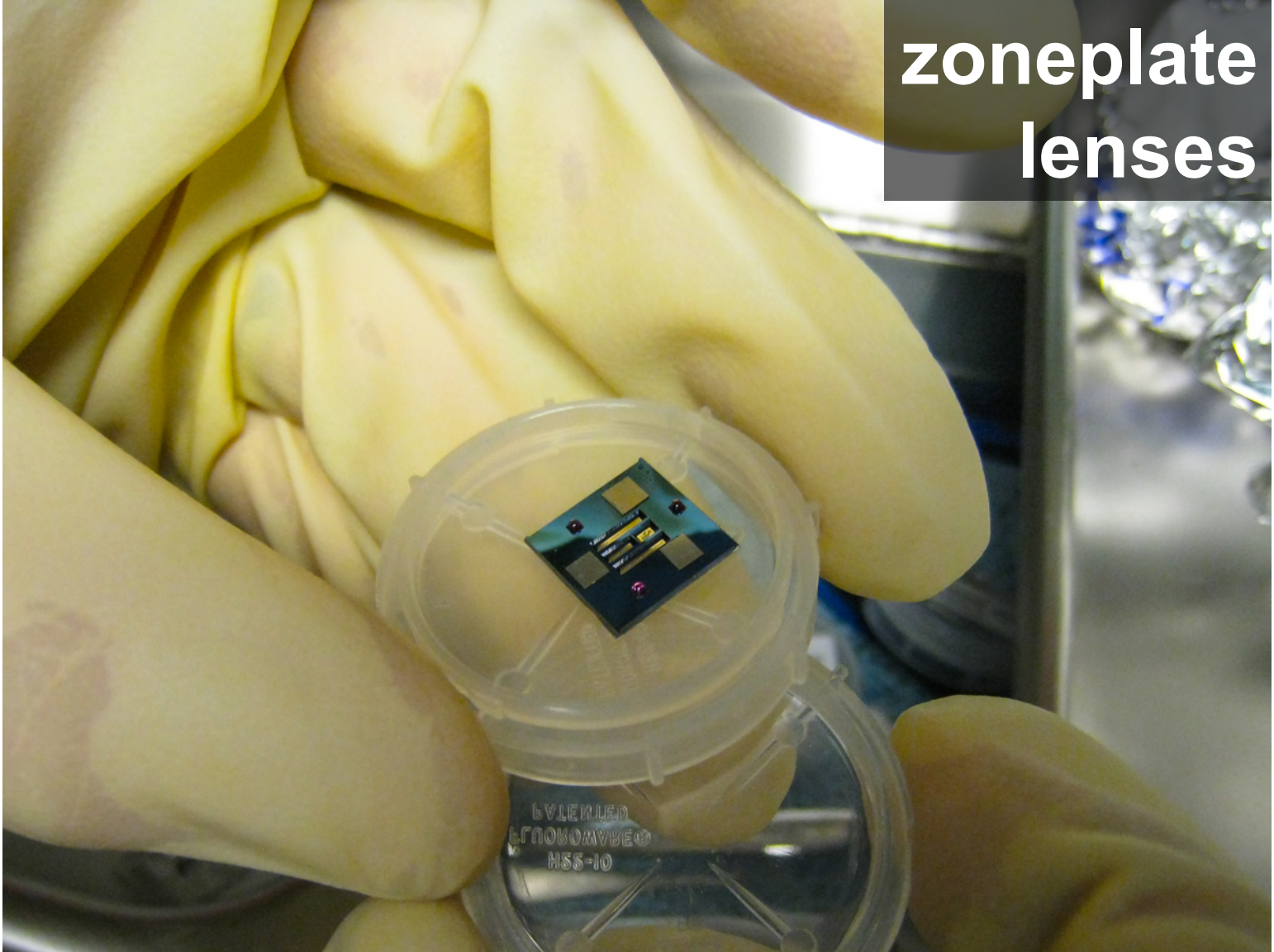
SHARP

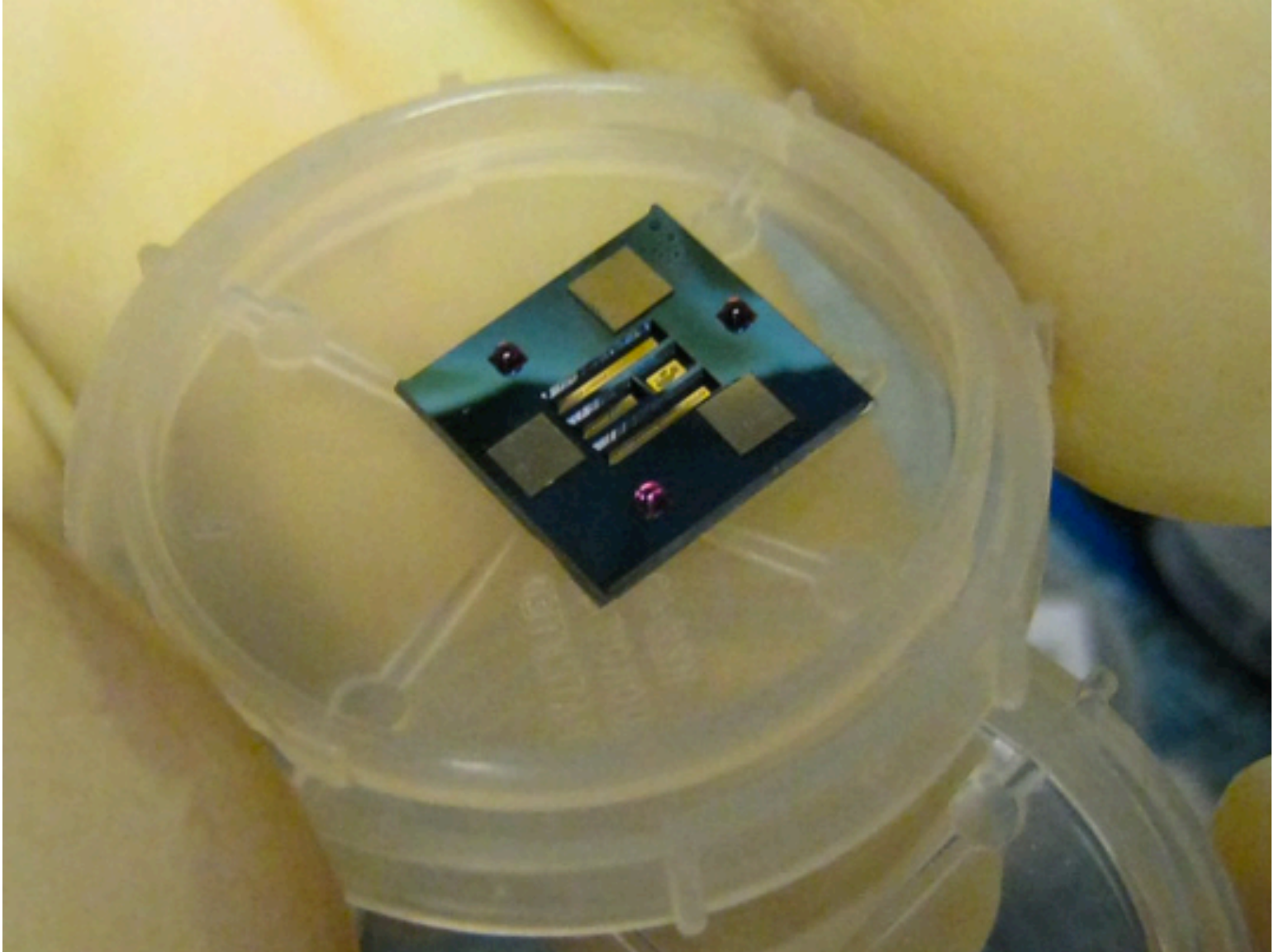
7 reflections,

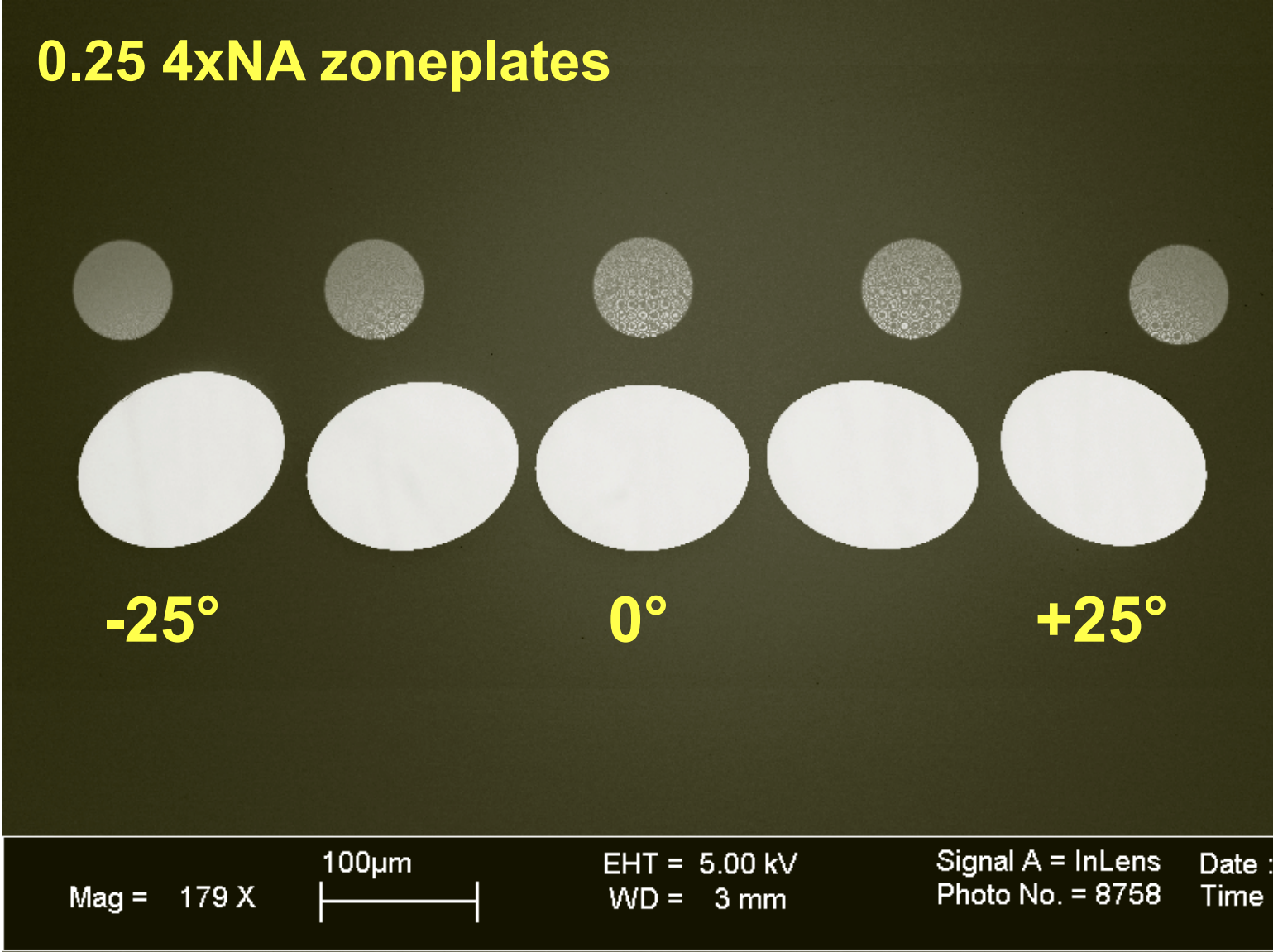
> 100x more power than AIT

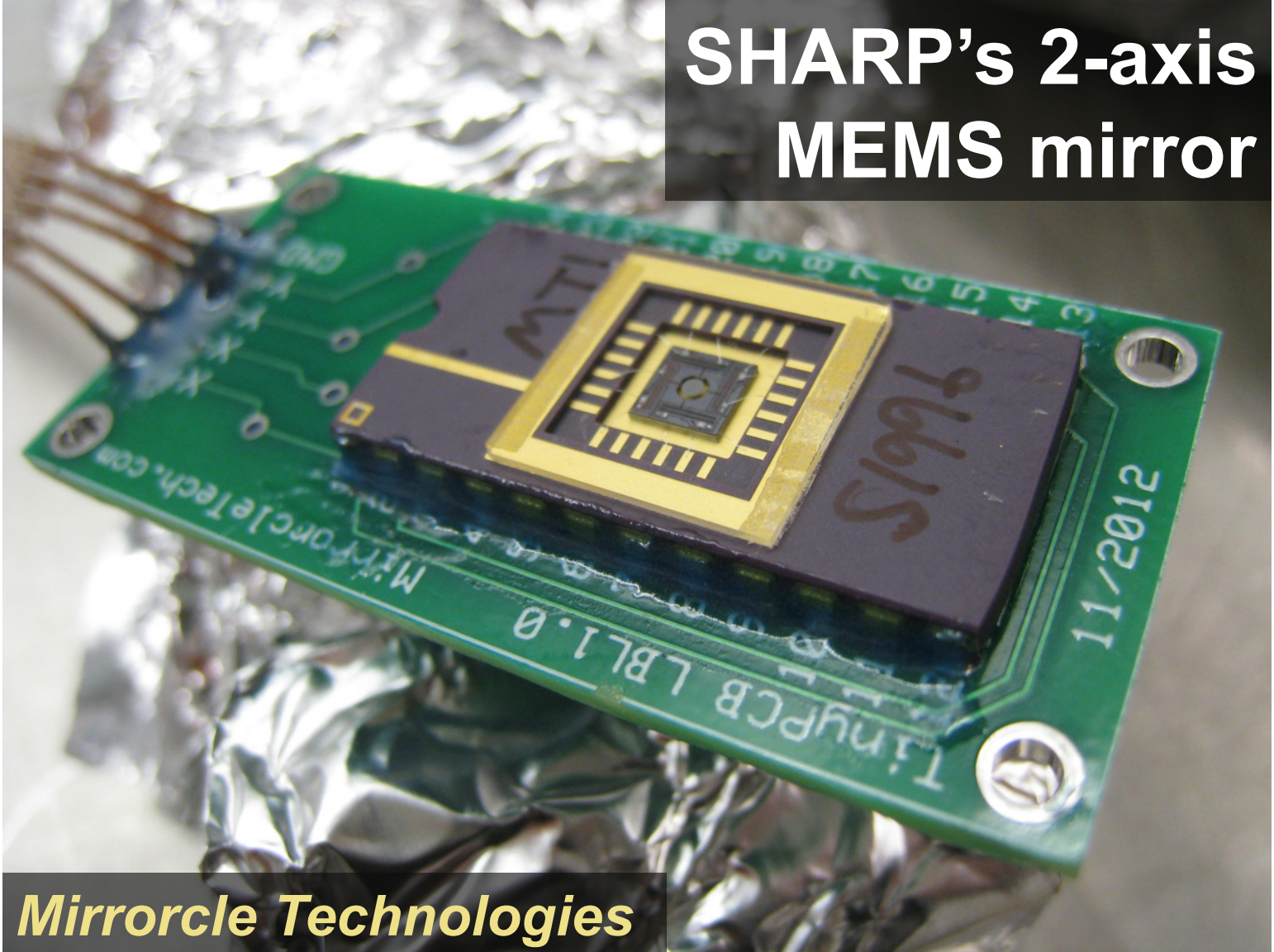
Not to scale

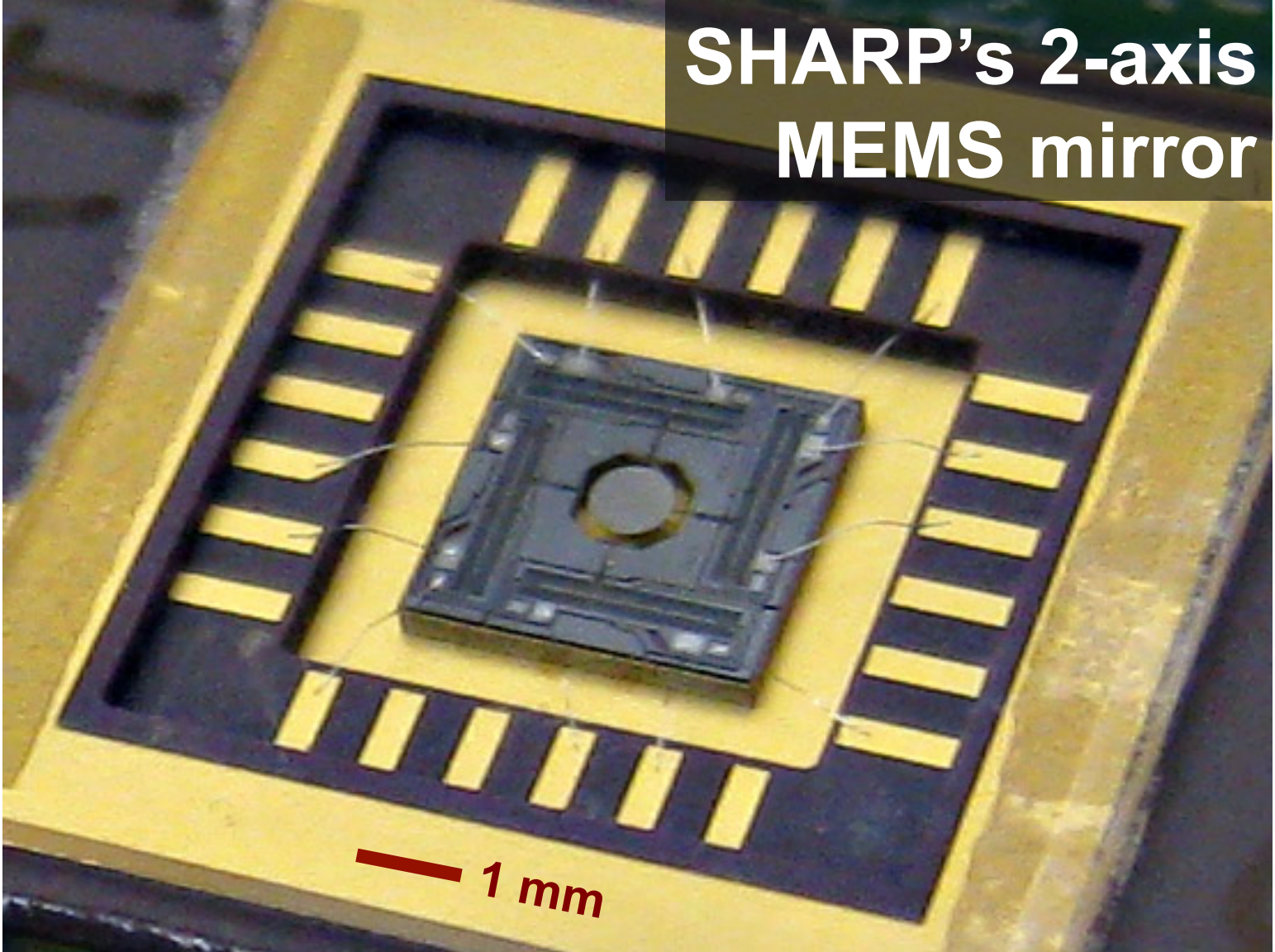

SHARP


zoneplate
lenses

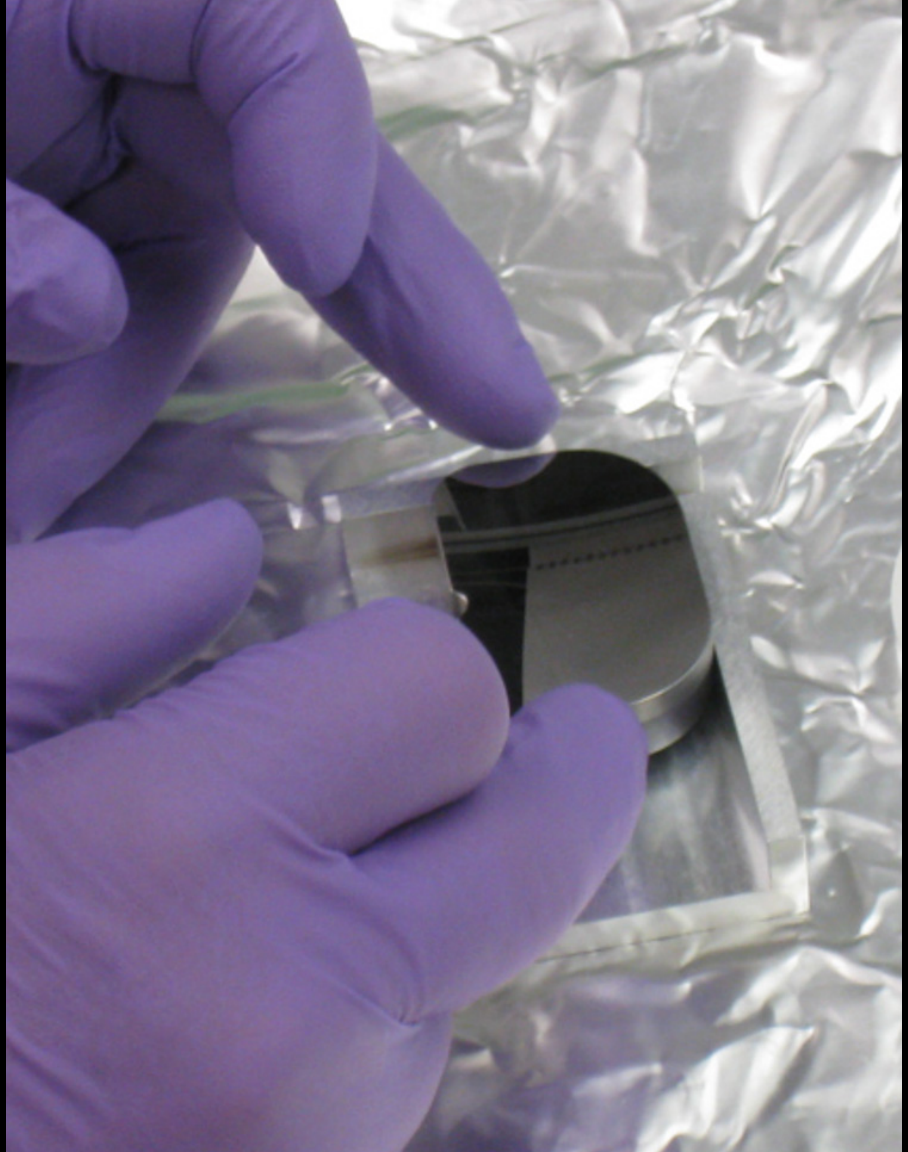



0.25 4xNA zoneplates
-25°
0°
+25°
Mag = 179 X
100µm
EHT = 5.00 kV
WD = 3 mm
Signal A = InLens
Photo No. = 8758
Date :
Time

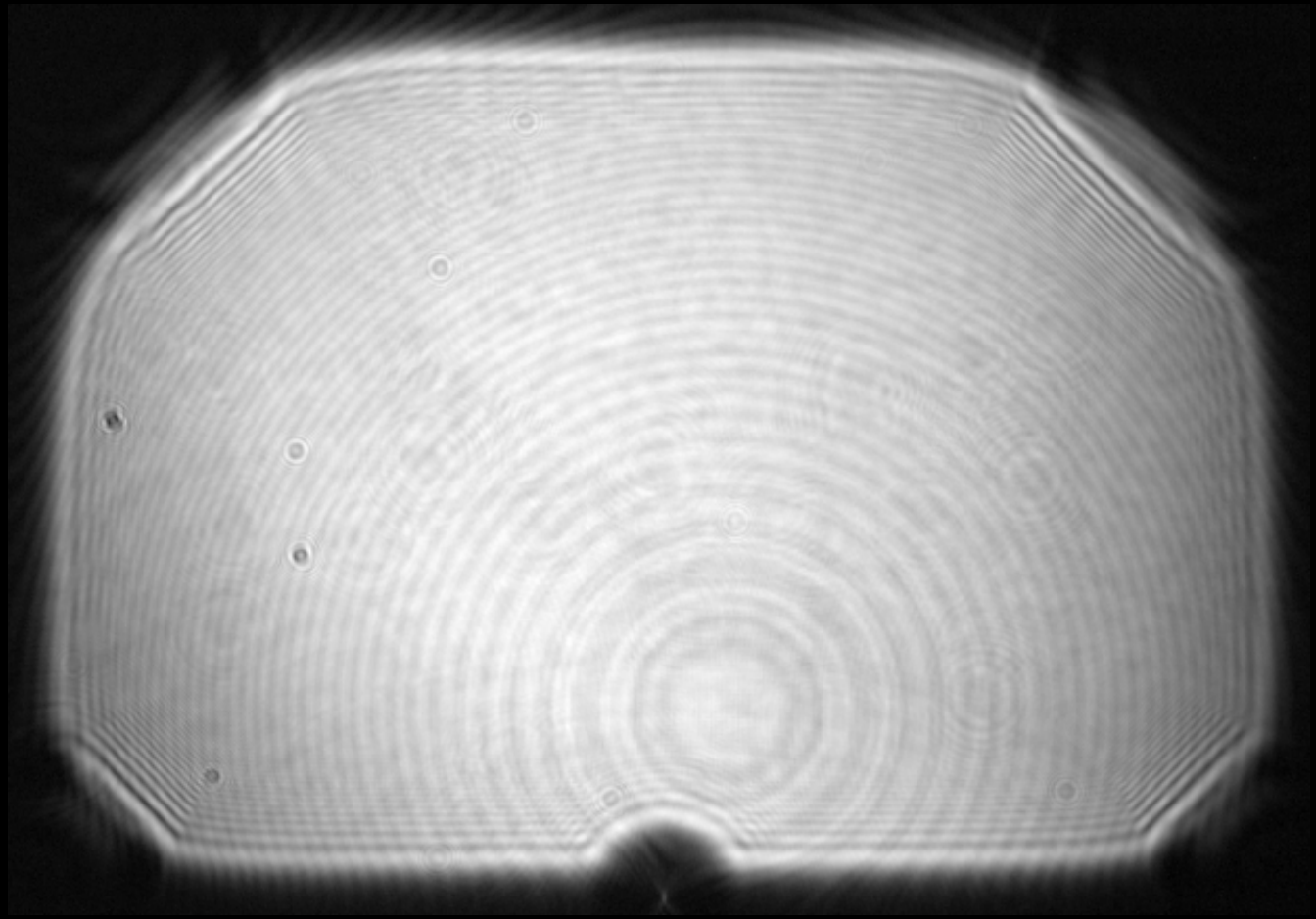

SHARP's 2-axis
MEMS mirror
Mirrorcle Technologies


SHARP's 2-axis
MEMS mirror
1 mm

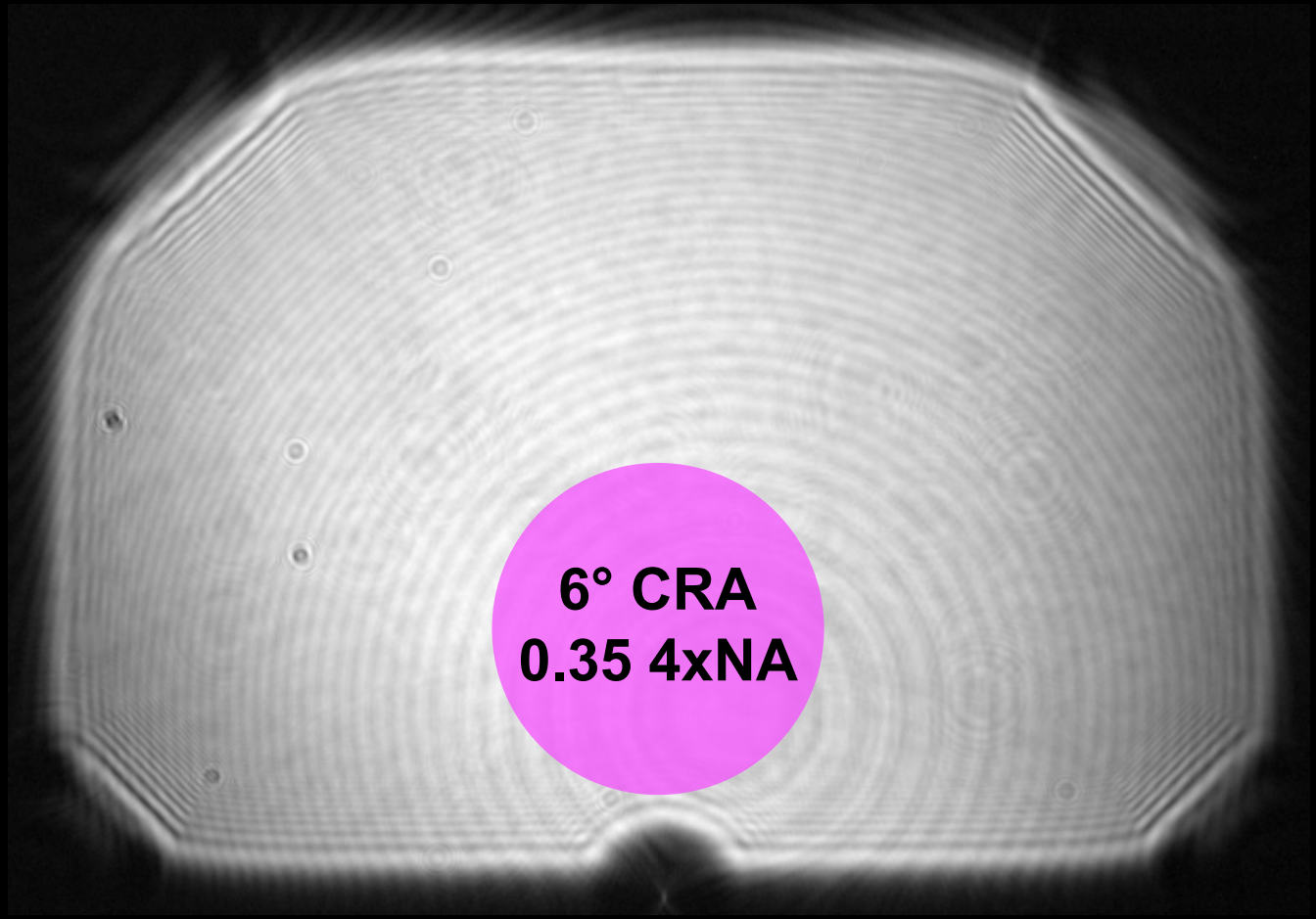

SHARP
Condenser
L-3 Tinsley



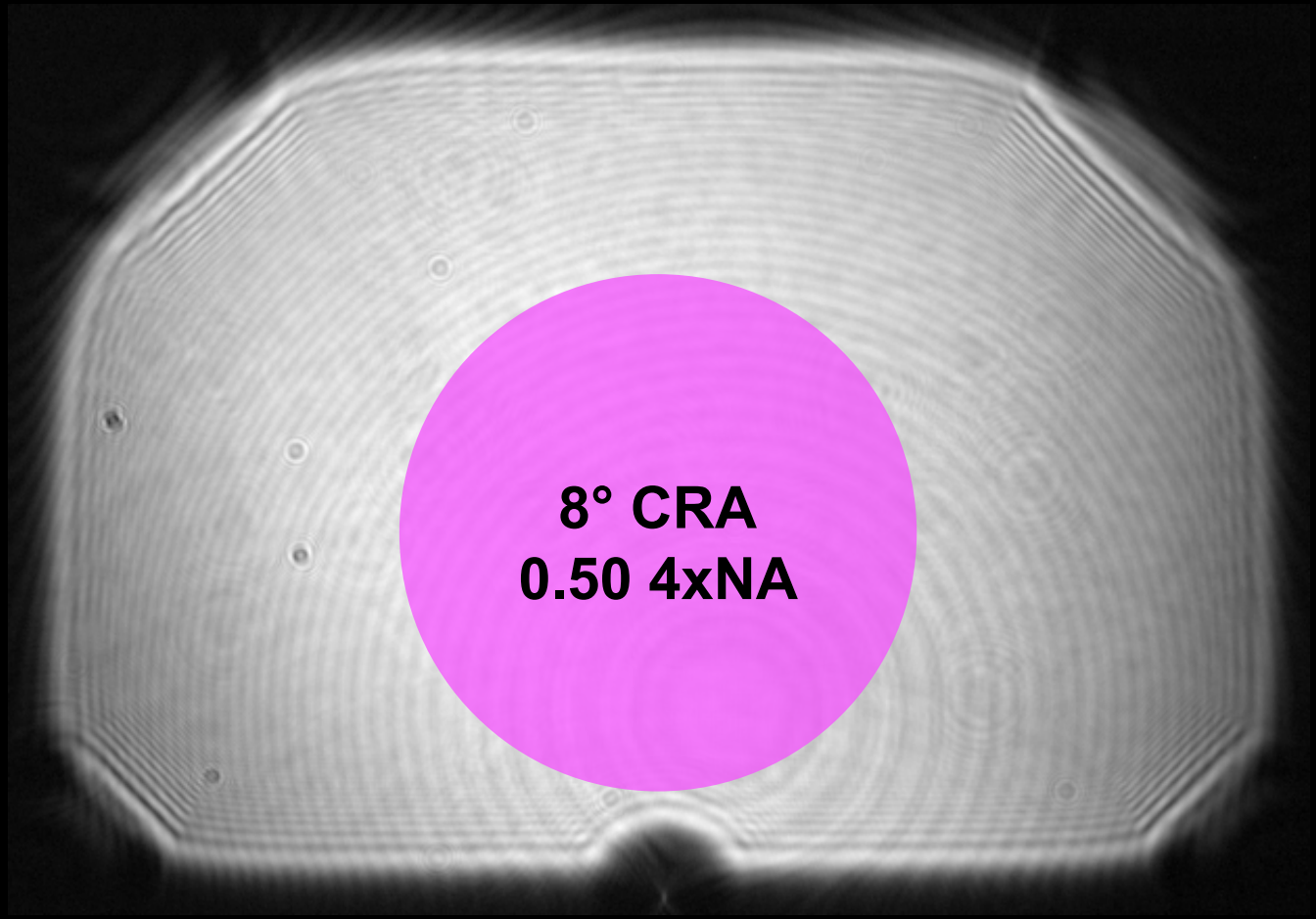
SHARP condenser



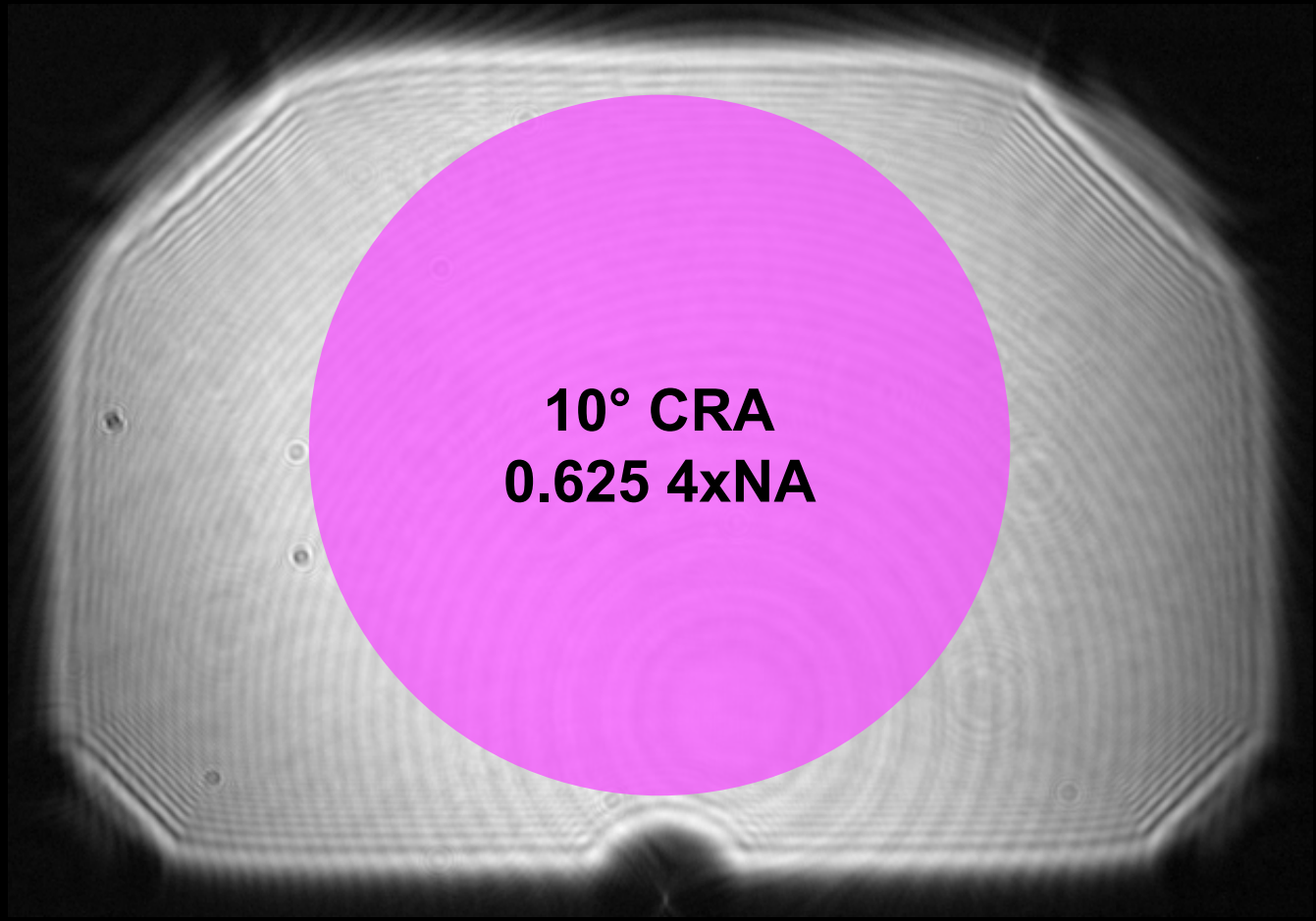
SHARP condenser



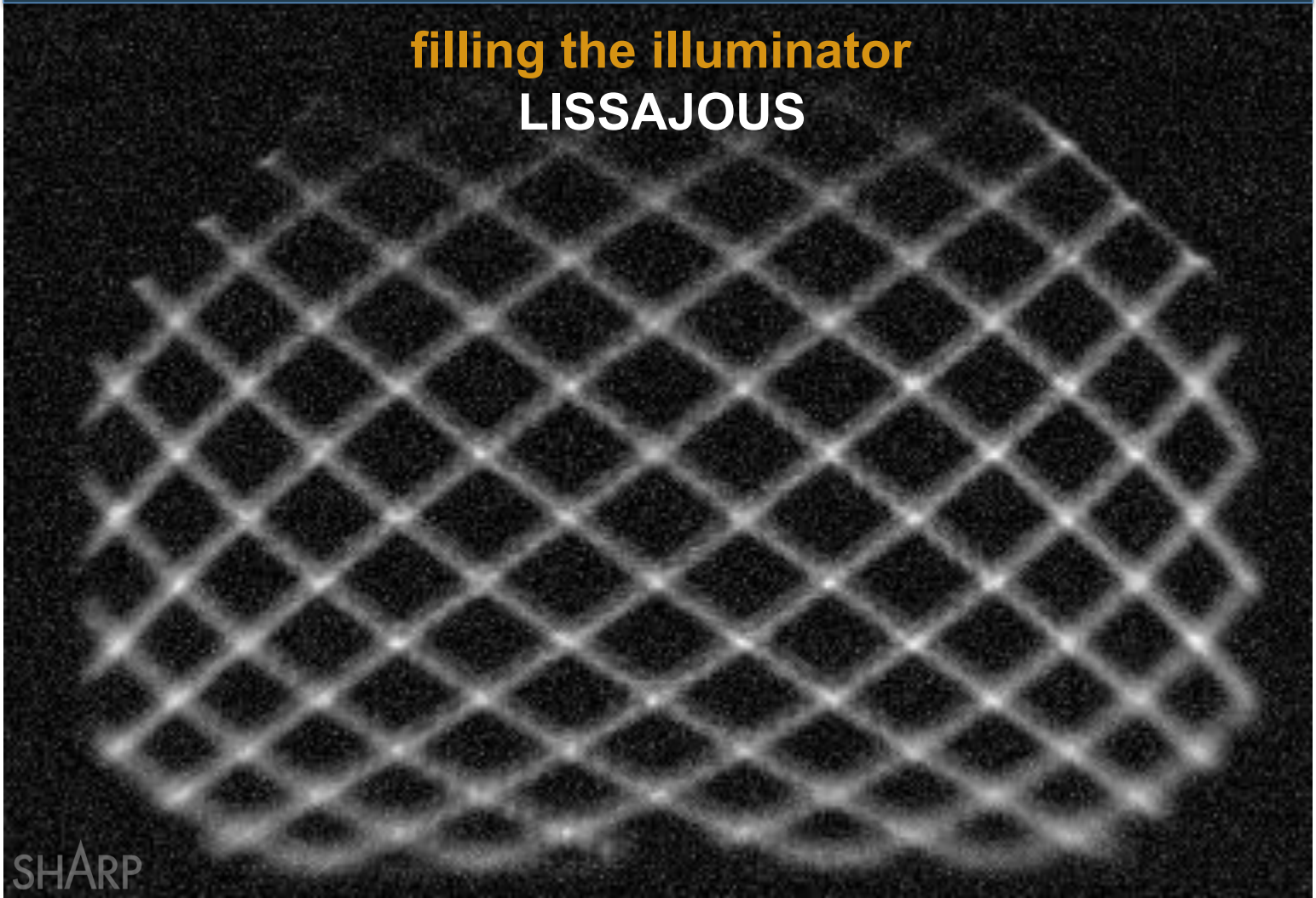
SHARP condenser



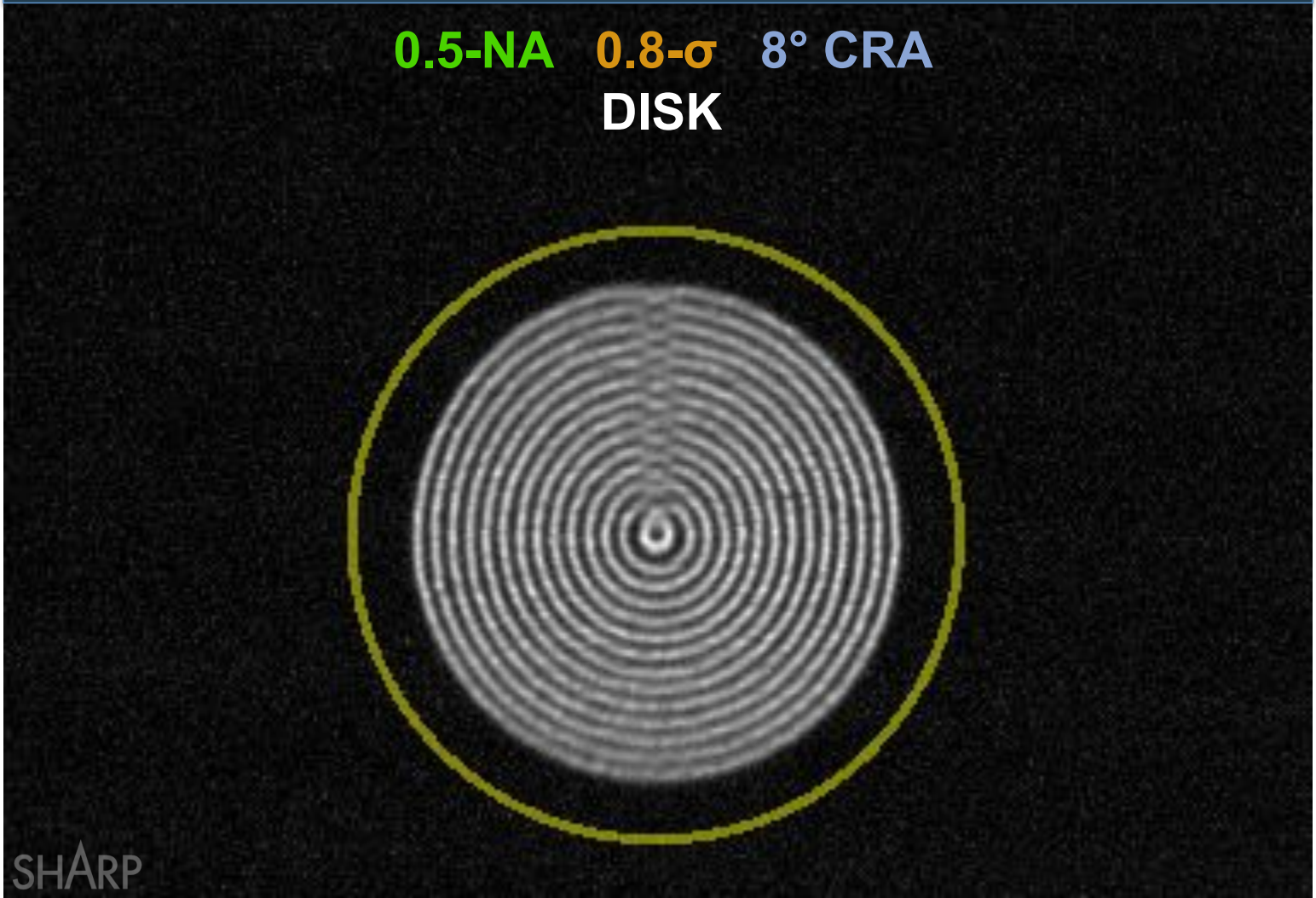
SHARP condenser



Coherence Control: Pupil Fill Patterns



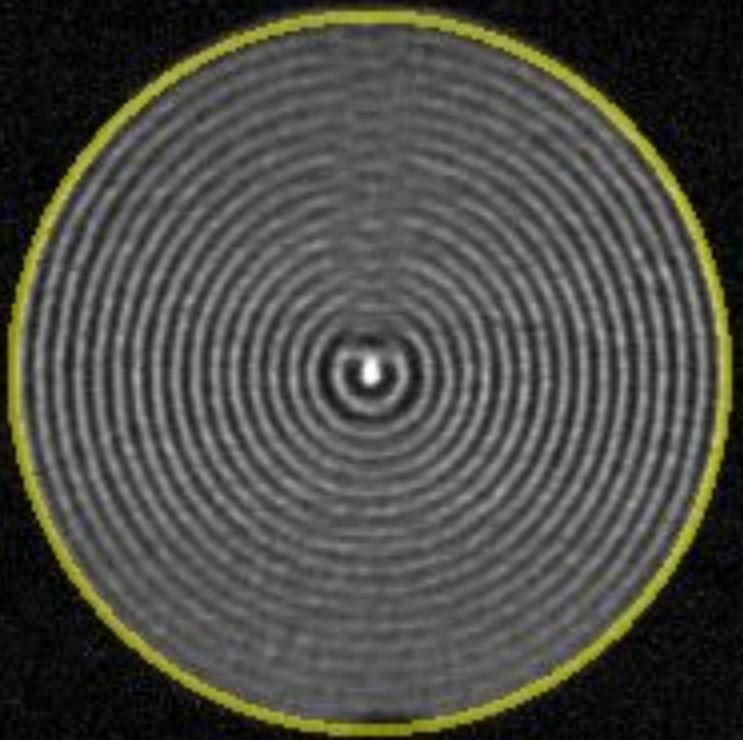
Coherence Control: Pupil Fill Patterns



Coherence Control: Pupil Fill Patterns

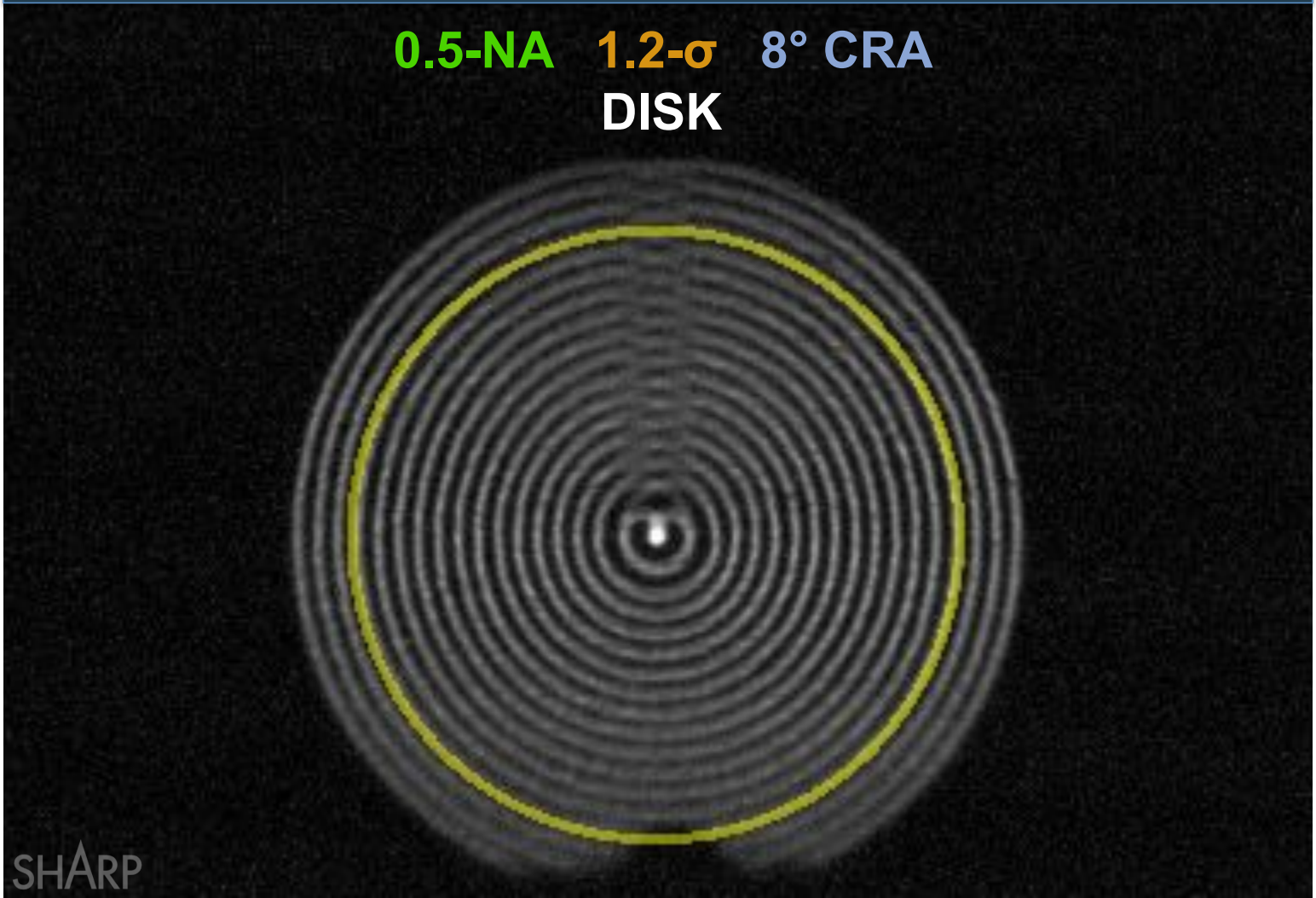
0.5-NA 1.0-σ 8° CRA

DISK

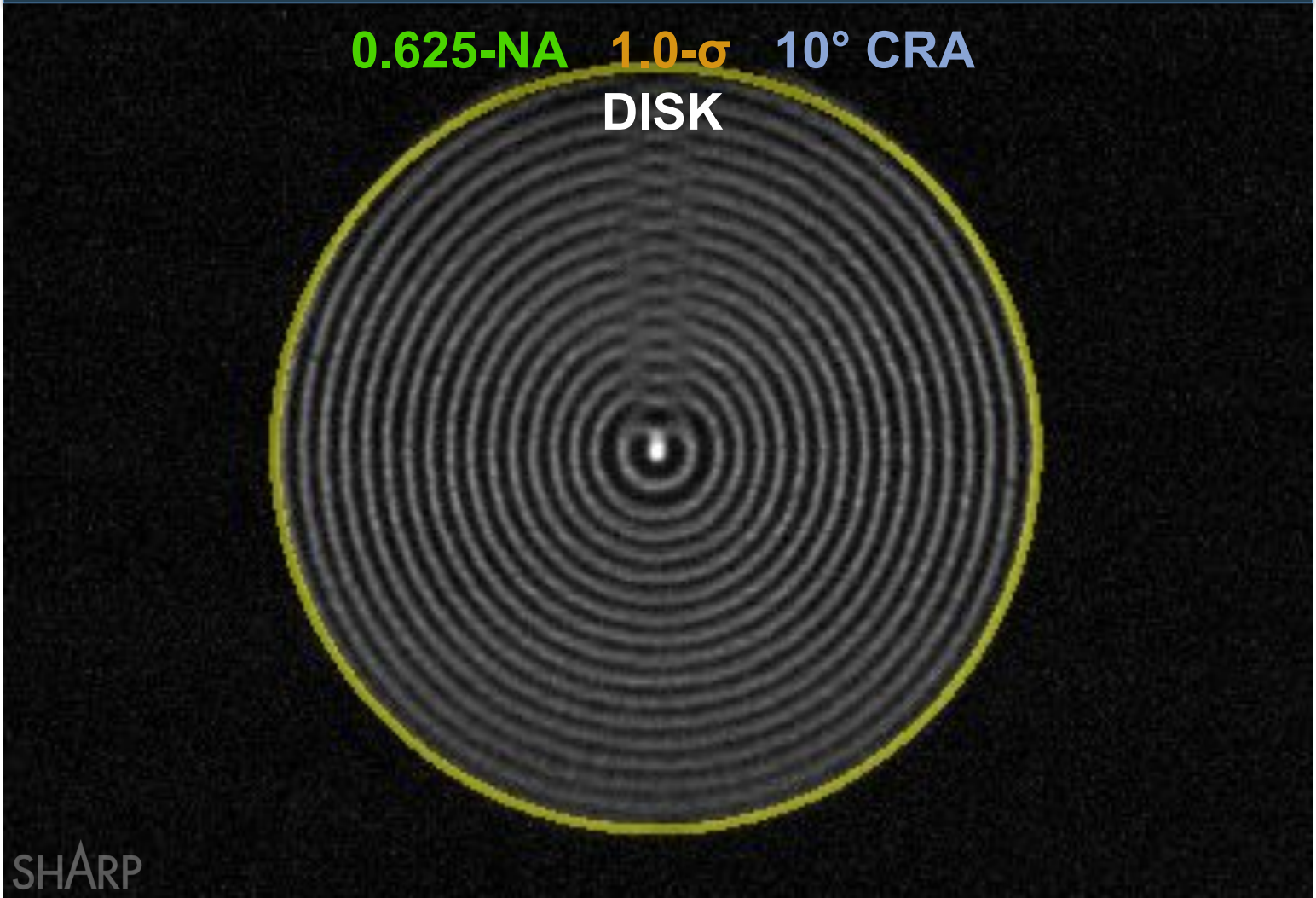


SHARP

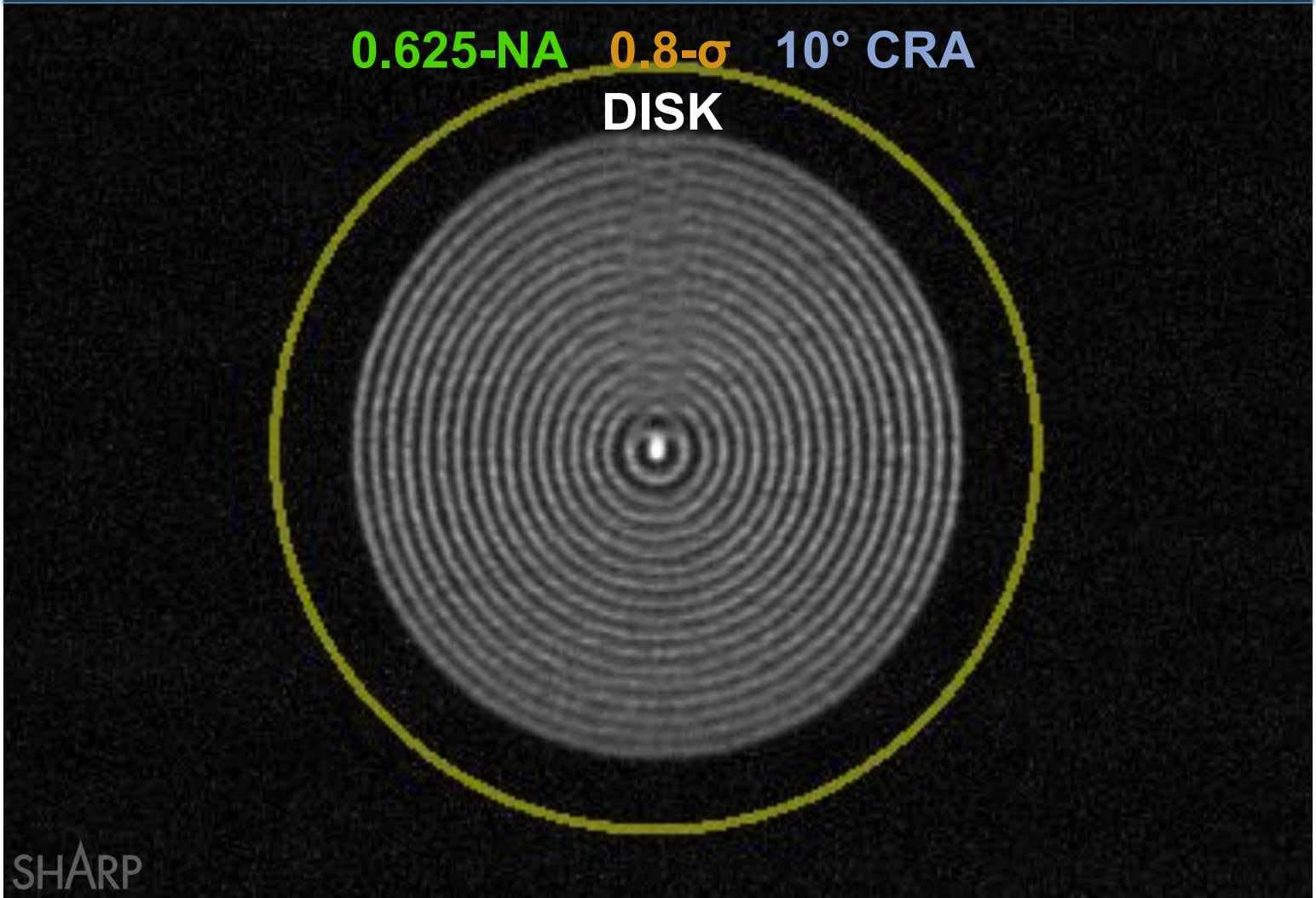
Coherence Control: Pupil Fill Patterns



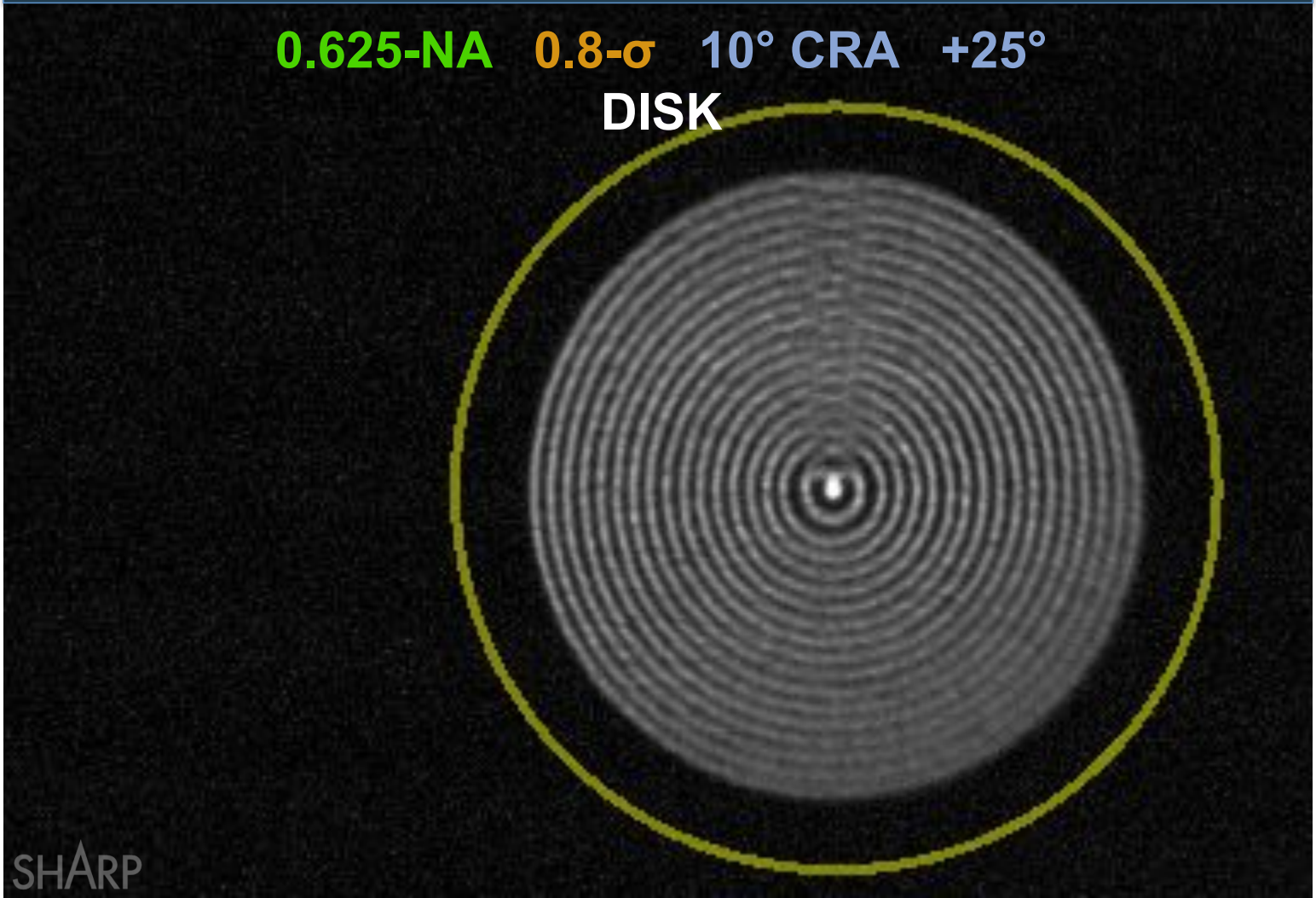
Coherence Control: Pupil Fill Patterns



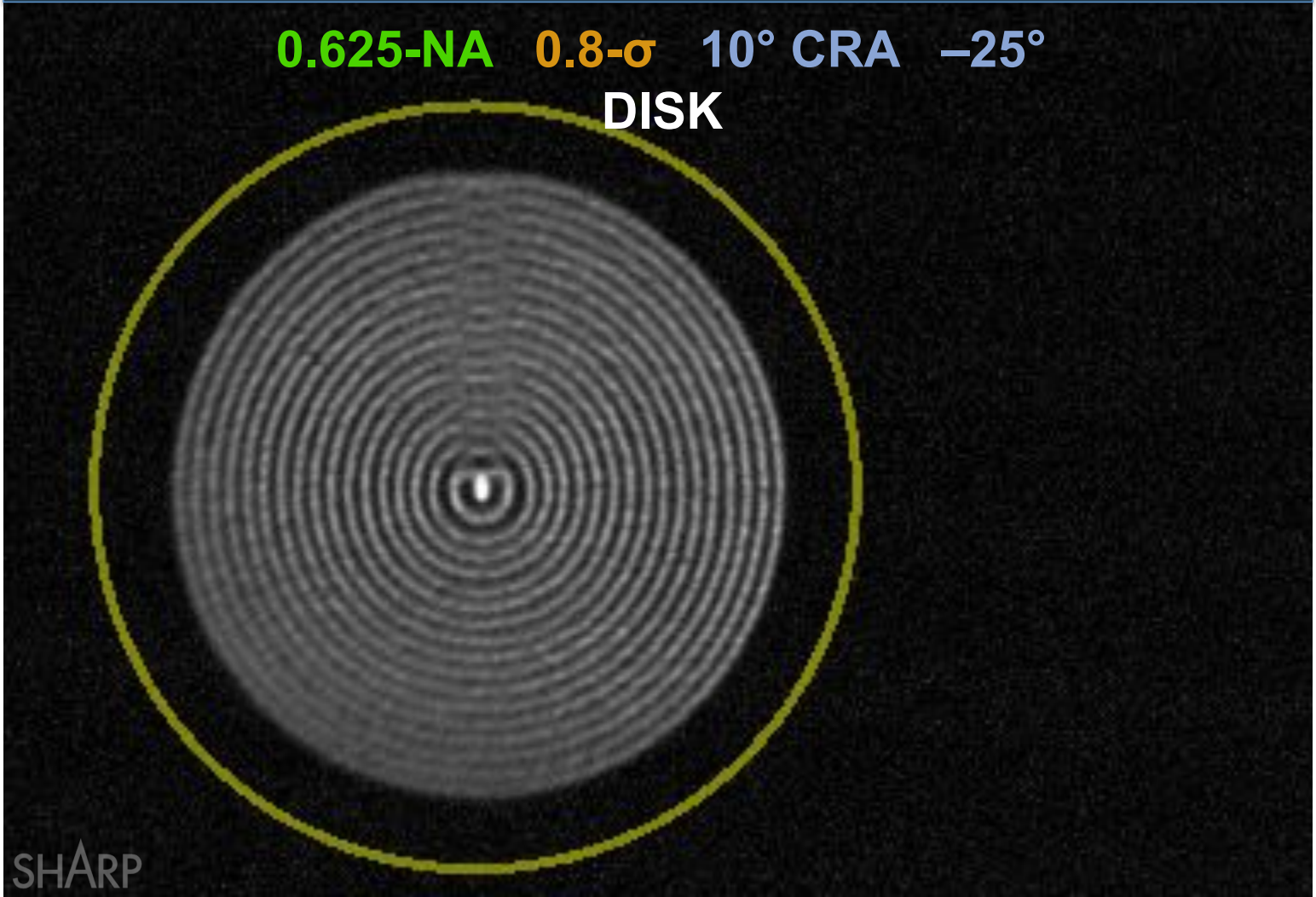
Coherence Control: Pupil Fill Patterns



Coherence Control: Pupil Fill Patterns



Coherence Control: Pupil Fill Patterns



Coherence Control: Pupil Fill Patterns

0.25-NA 1.0-σ 6° CRA

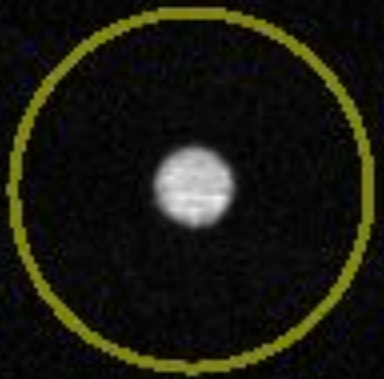
DISK

SHARP

Coherence Control: Pupil Fill Patterns

0.25-NA 0.2-σ 6° CRA

DISK



SHARP

Coherence Control: Pupil Fill Patterns

0.25-NA 0.05-σ 6° CRA

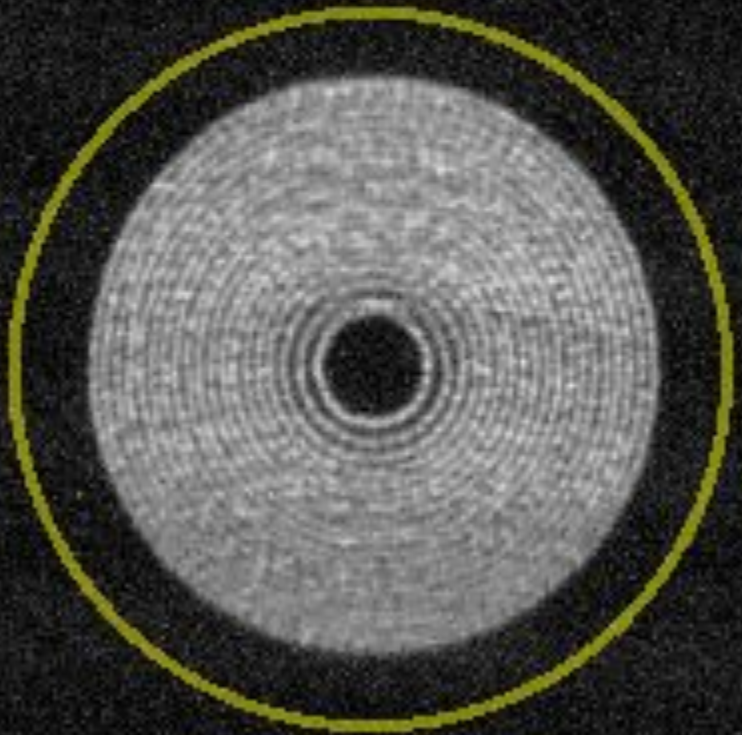
DISK

SHARP

Coherence Control: Pupil Fill Patterns

0.5-NA 0.2–0.8-σ 8° CRA

ANNULAR



SHARP

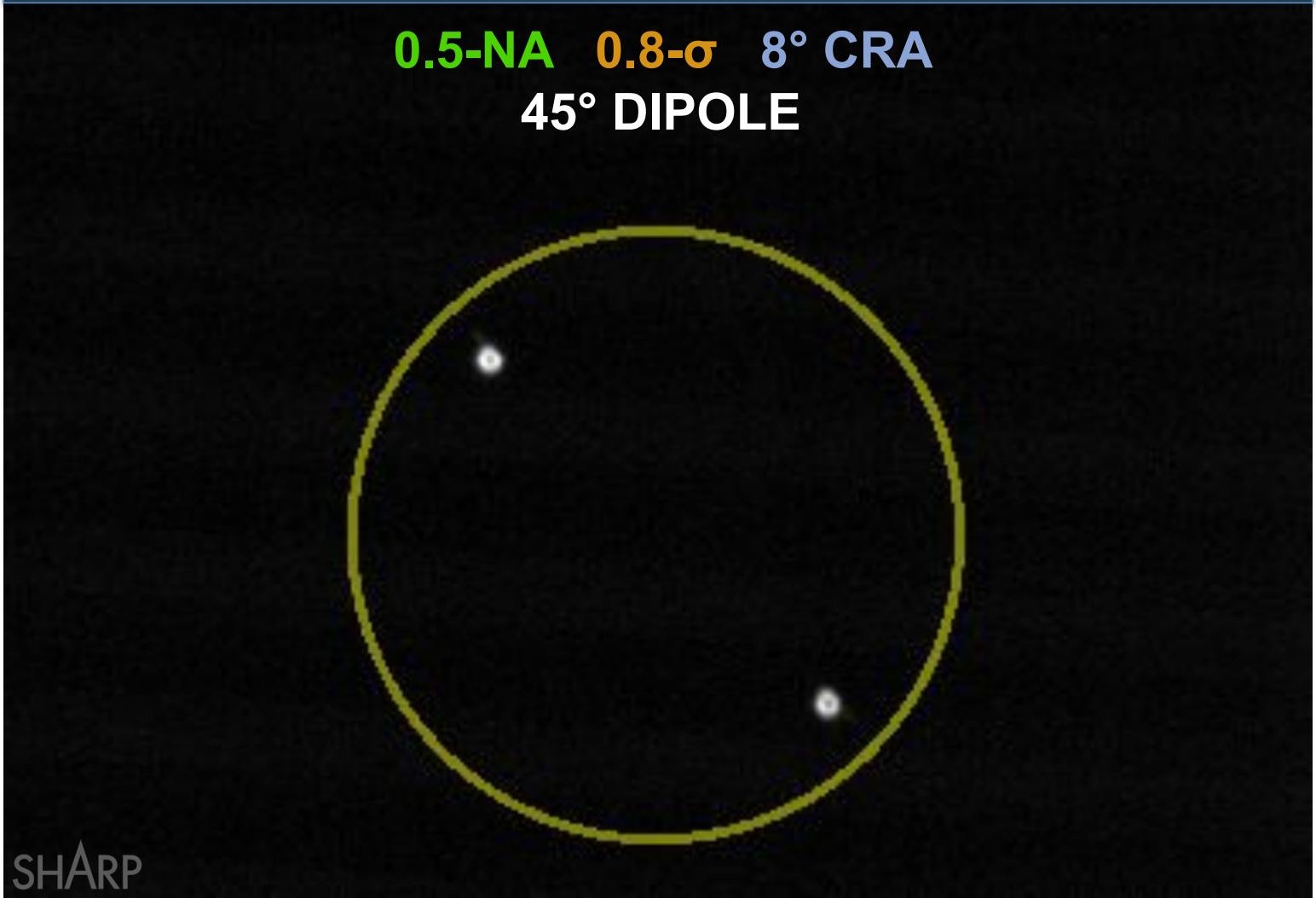
Coherence Control: Pupil Fill Patterns

0.5-NA 0.8-σ 8° CRA

DIPOLE

SHARP

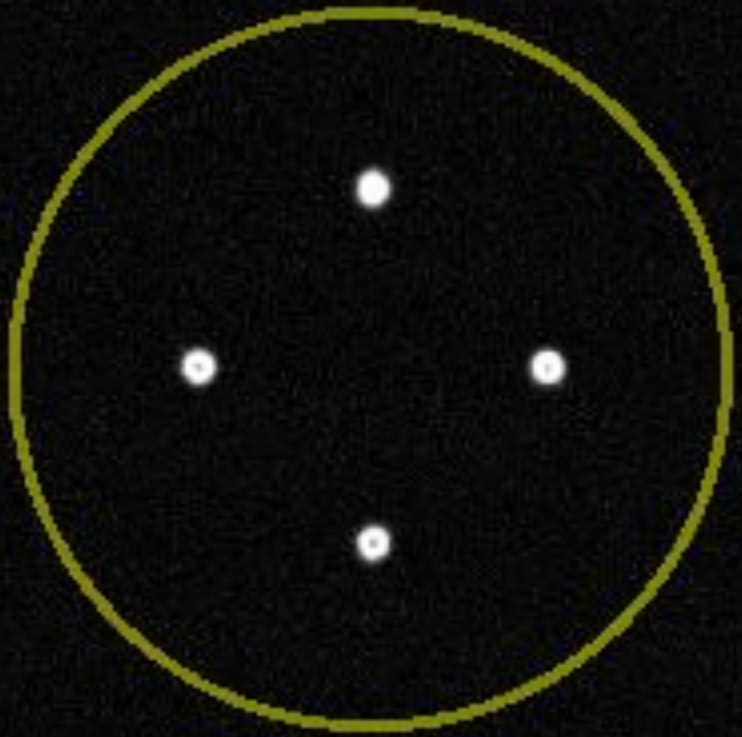
Coherence Control: Pupil Fill Patterns



Coherence Control: Pupil Fill Patterns

0.5-NA 0.5-σ 8° CRA

QUADRUPOLE

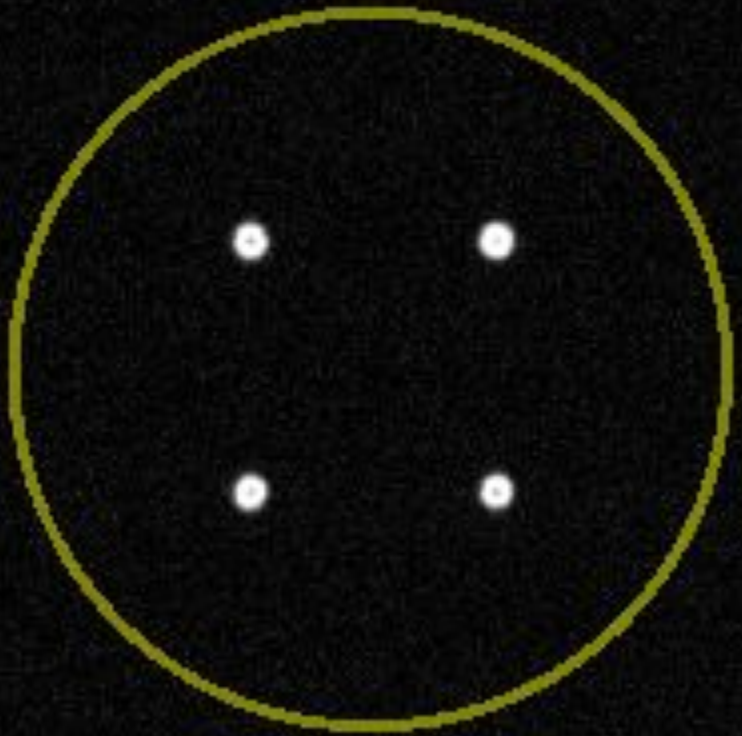


SHARP

Coherence Control: Pupil Fill Patterns

0.5-NA 0.5-σ 8° CRA

45° QUADRUPOLE



SHARP

Coherence Control: Pupil Fill Patterns

0.5-NA 0.8-σ 8° CRA

CROSSPOLE (22.5° arc)

SHARP

Coherence Control: Pupil Fill Patterns

0.5-NA 0.8-σ 8° CRA

CROSSPOLE (45° arc)

SHARP

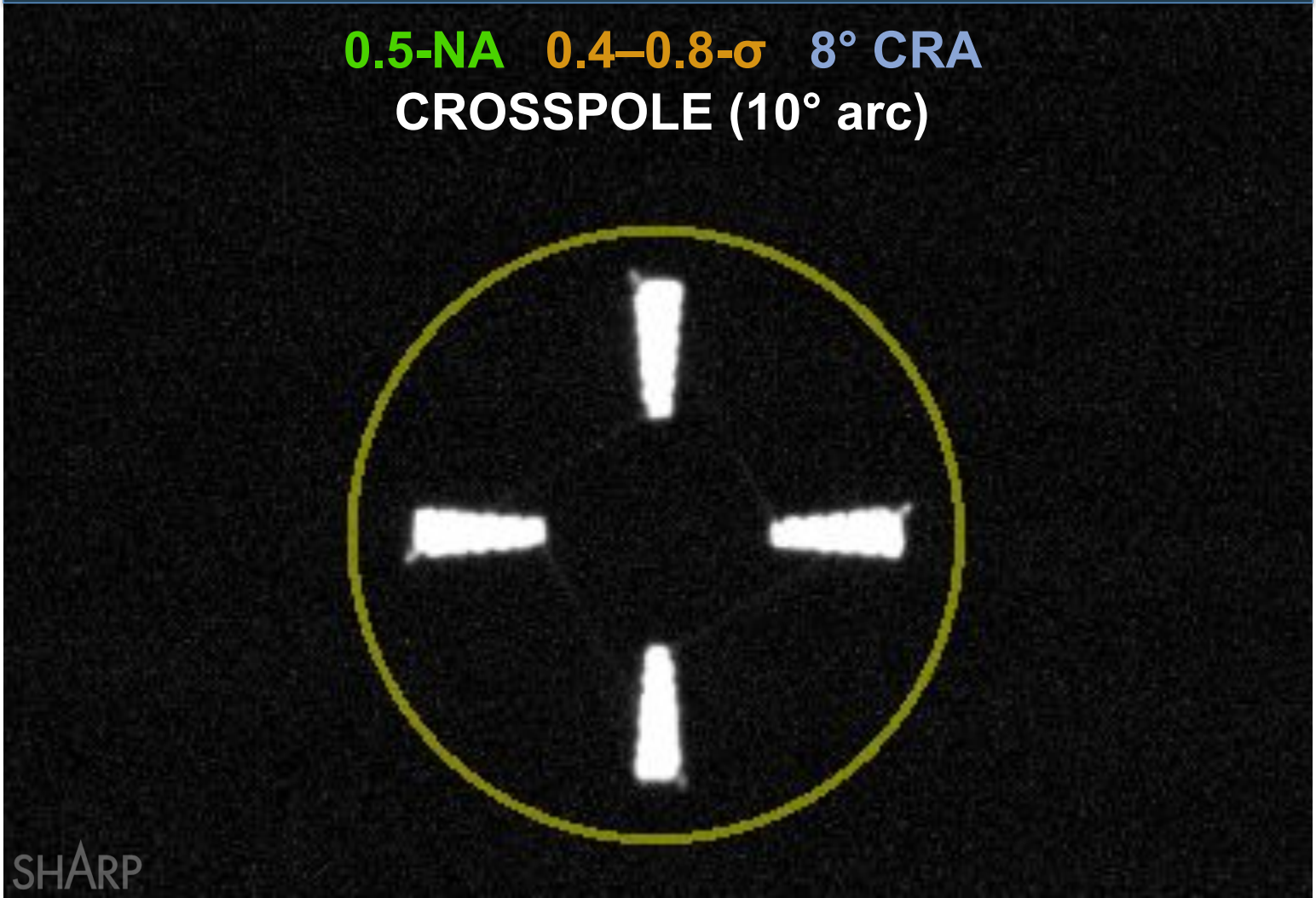
Coherence Control: Pupil Fill Patterns

0.5-NA 0.4–0.8-σ 8° CRA

CROSSPOLE (45° arc)

SHARP

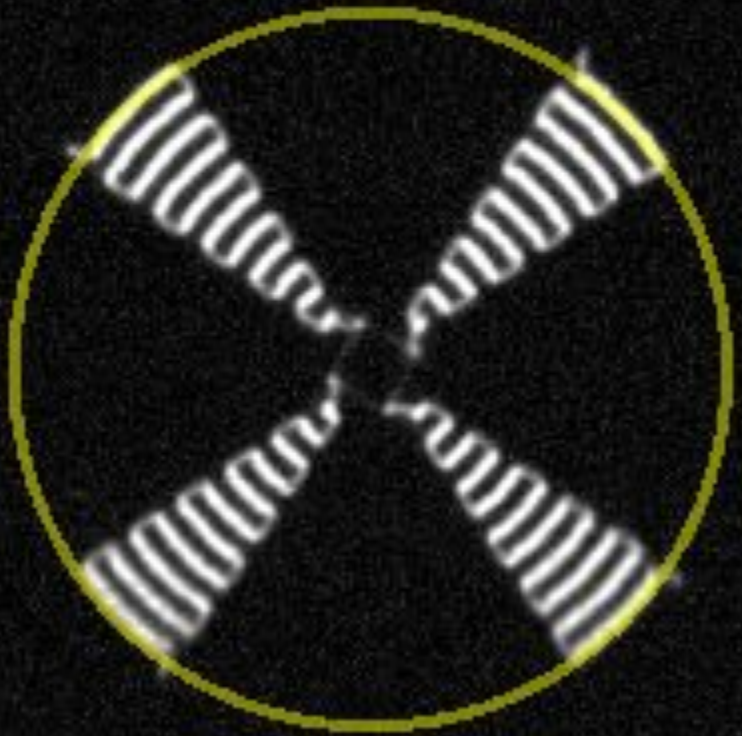
Coherence Control: Pupil Fill Patterns



Coherence Control: Pupil Fill Patterns

0.5-NA 0.1–1.0-σ 8° CRA

45° CROSSPOLE (22.5° arc)

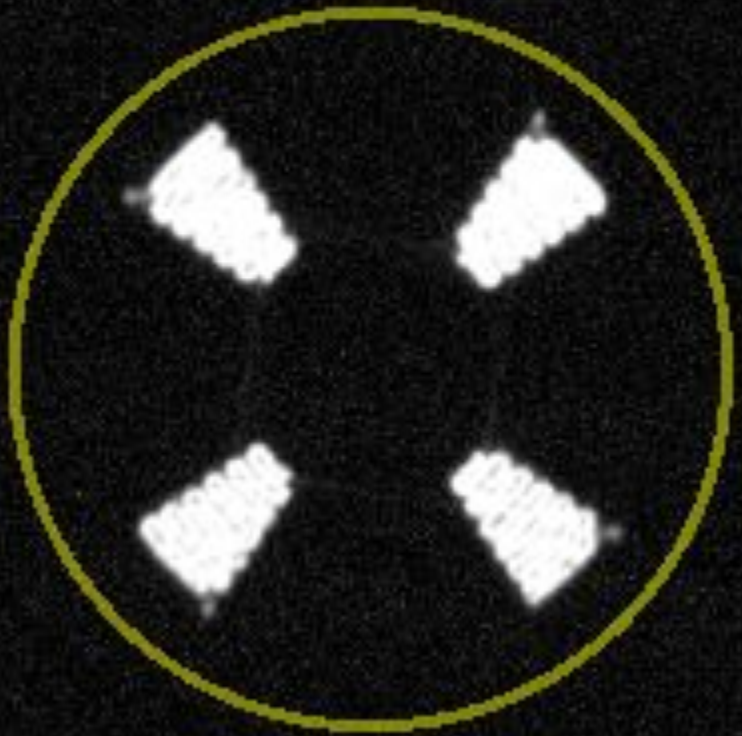


SHARP

Coherence Control: Pupil Fill Patterns

0.5-NA 0.4–0.8-σ 8° CRA

45° CROSSPOLE (22.5° arc)

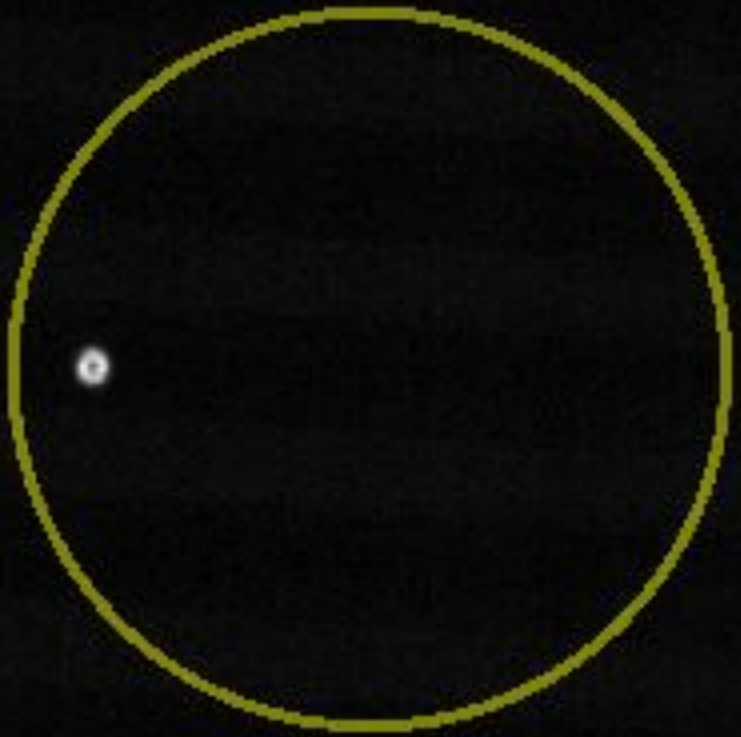


SHARP

Coherence Control: Pupil Fill Patterns

0.5-NA 0.8-σ 8° CRA

X MONOPOLE

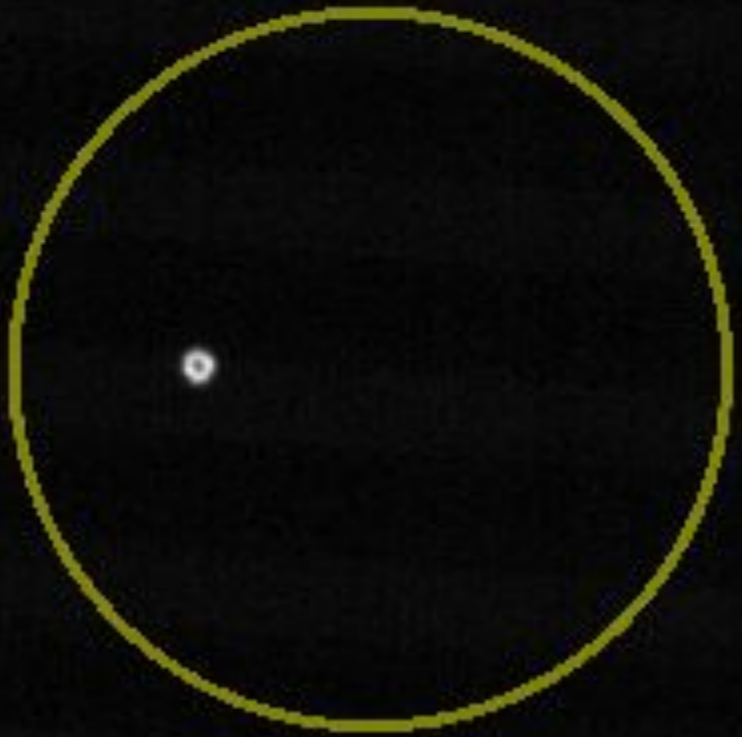


SHARP

Coherence Control: Pupil Fill Patterns

0.5-NA 0.5-σ 8° CRA

X MONOPOLE

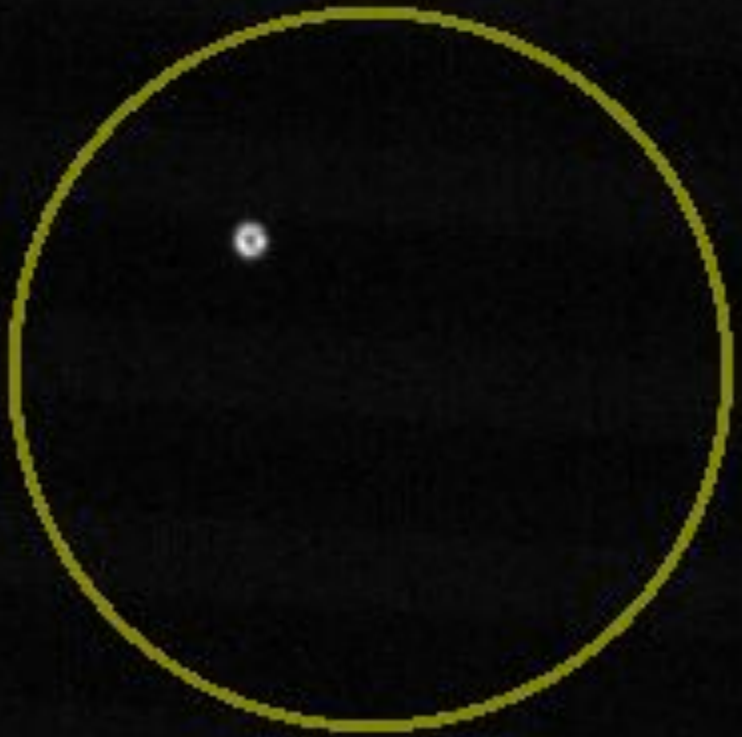


SHARP

Coherence Control: Pupil Fill Patterns

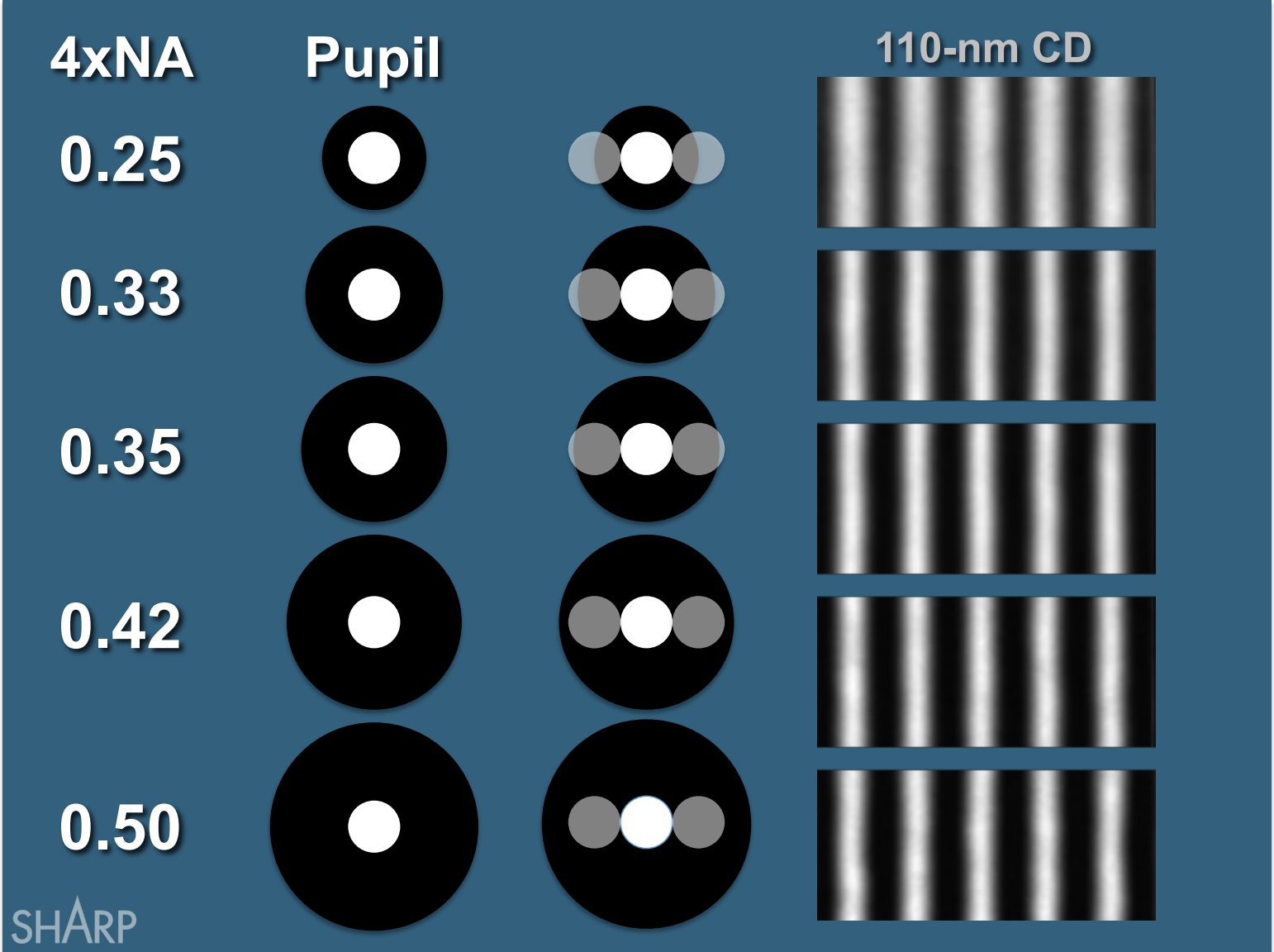
0.5-NA 0.5-σ 8° CRA

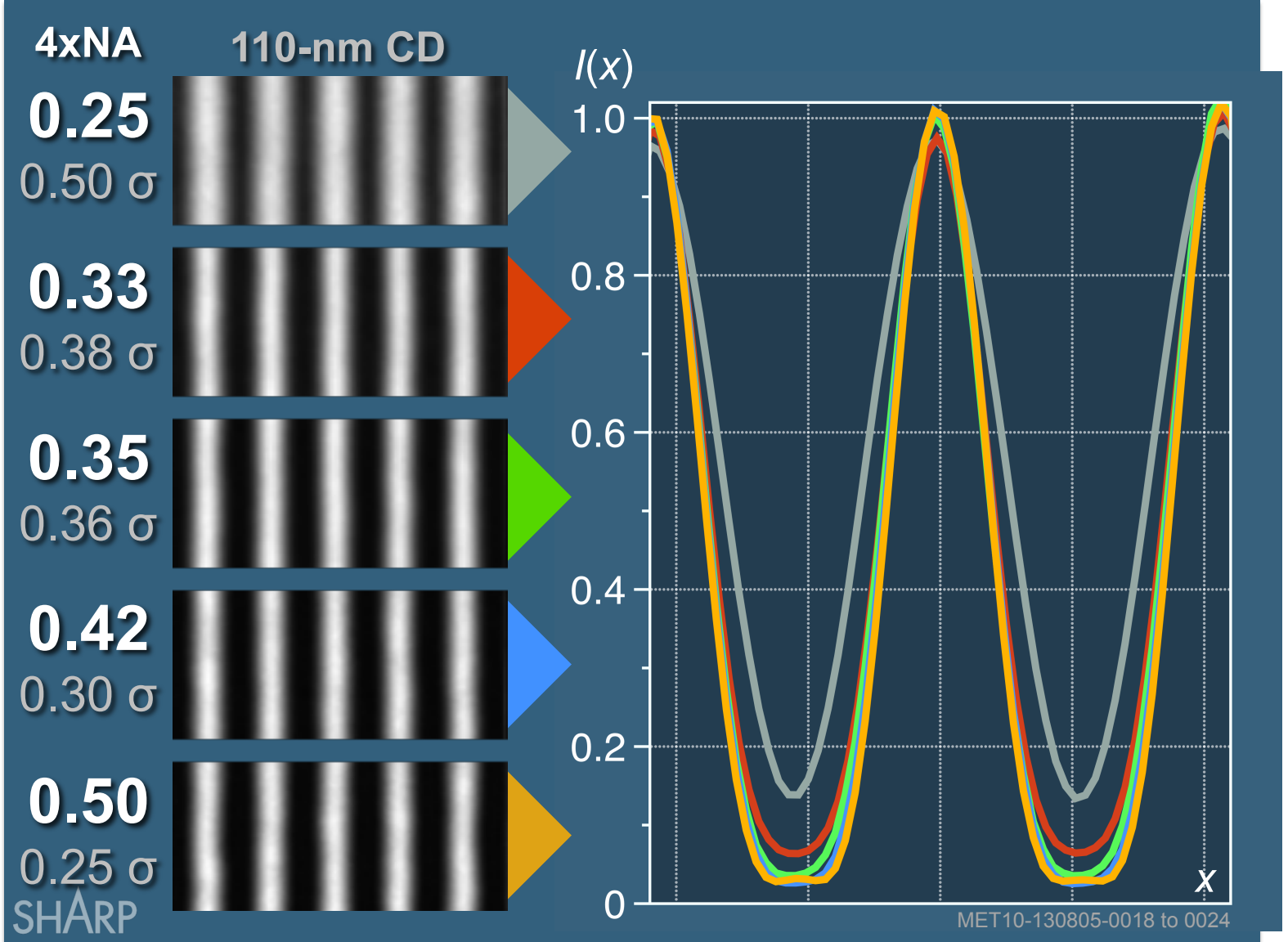
45° MONOPOLE



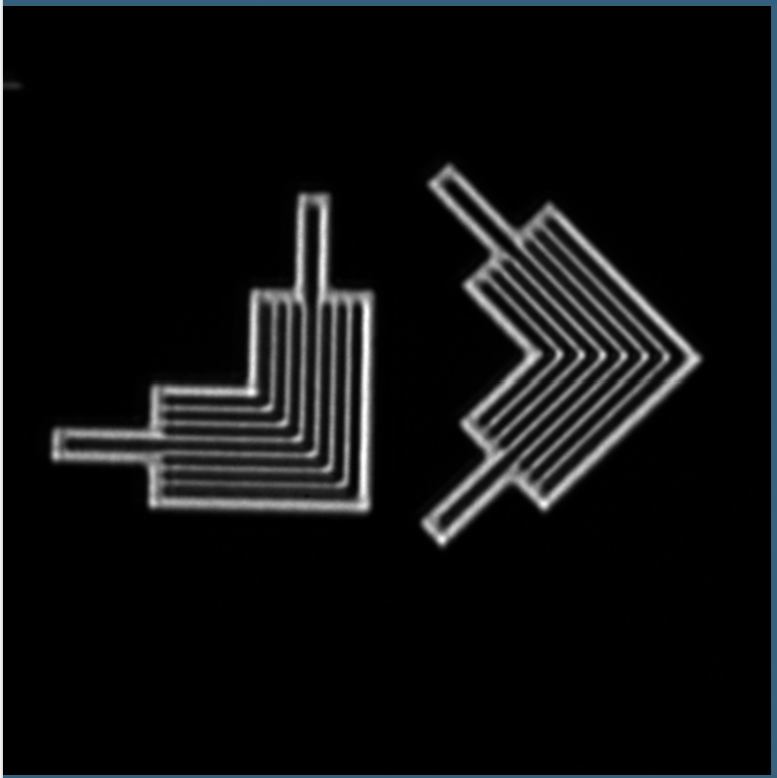
SHARP

High NA
for high spatial resolution


4xNA
Pupil
110-nm CD
0.25
0.33
0.35
0.42
0.50
SHARP


4xNA
110-nm CD
0.25
0.50 σ
0.33
0.38 σ
0.35
0.36 σ
0.42
0.30 σ
0.50
0.25 σ
SHARP
I(x)
1.0
0.8
0.6
0.4
0.2
0
x
MET10-130805-0018 to 0024

Pupil-fill affects imaging

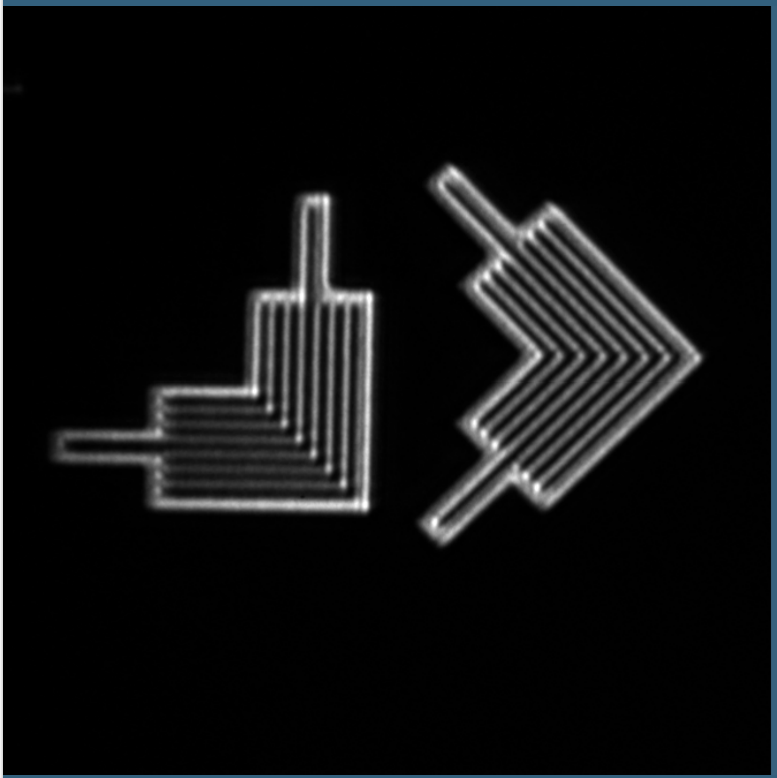


Elbows, 100-nm CD

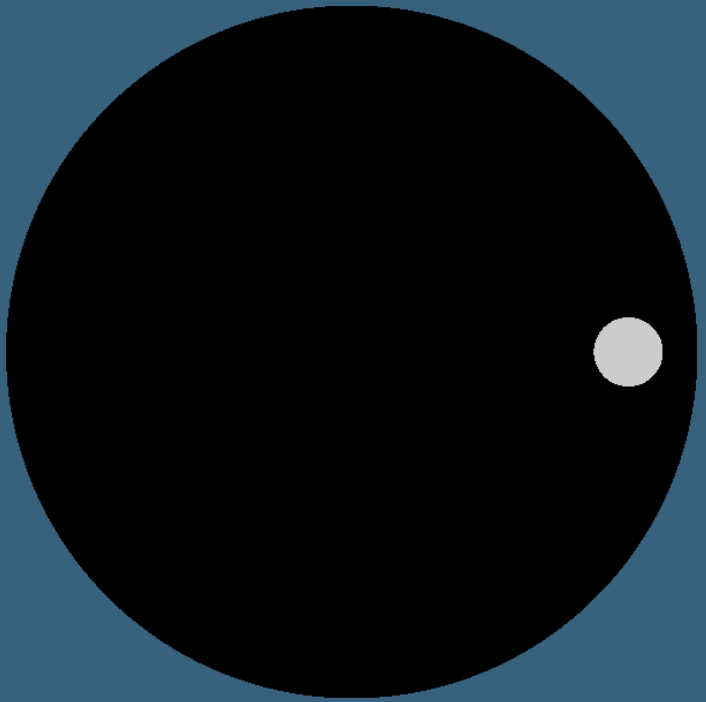
0.33 4xNA pupil

SHARP

Pupil-fill affects imaging



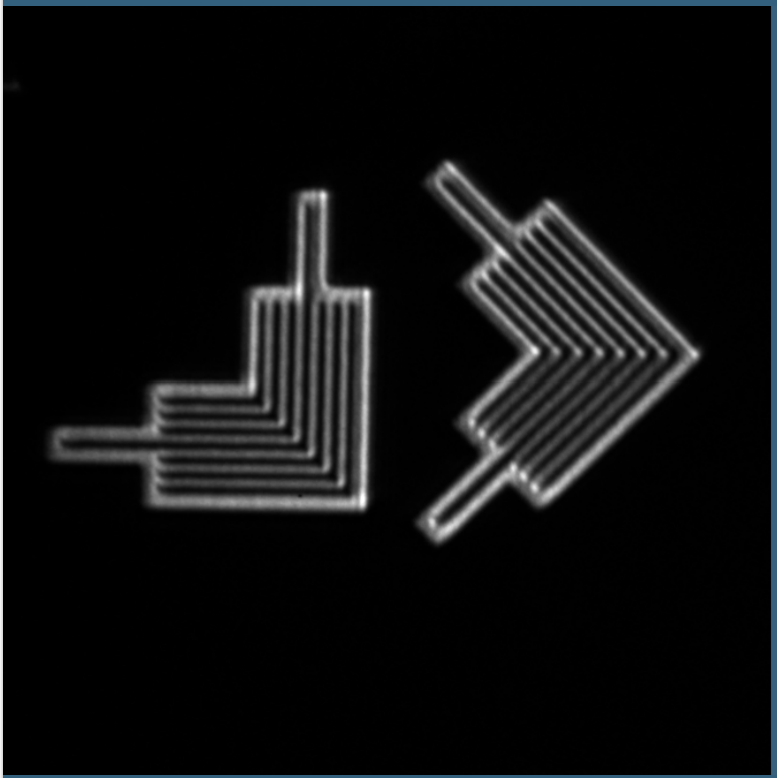
Elbows, 100-nm CD



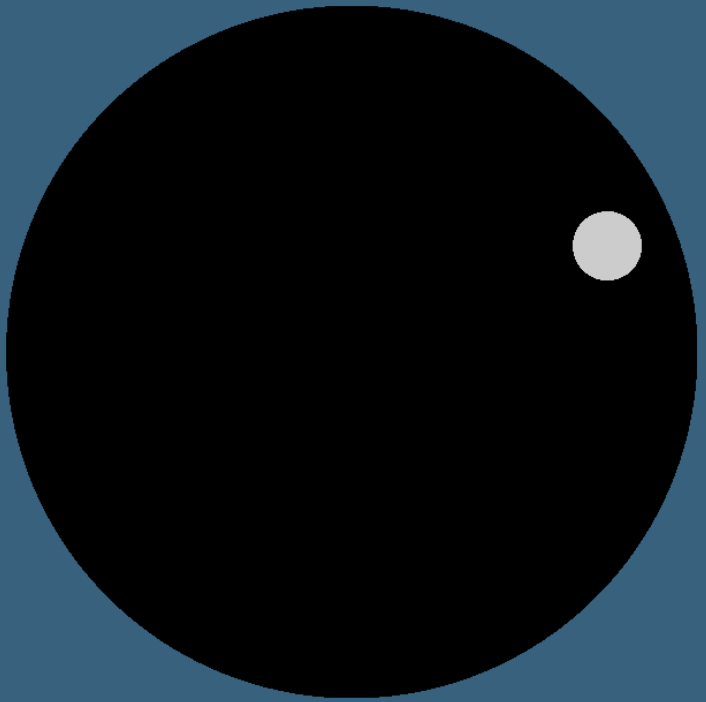
0.33 4xNA pupil

SHARP

Pupil-fill affects imaging



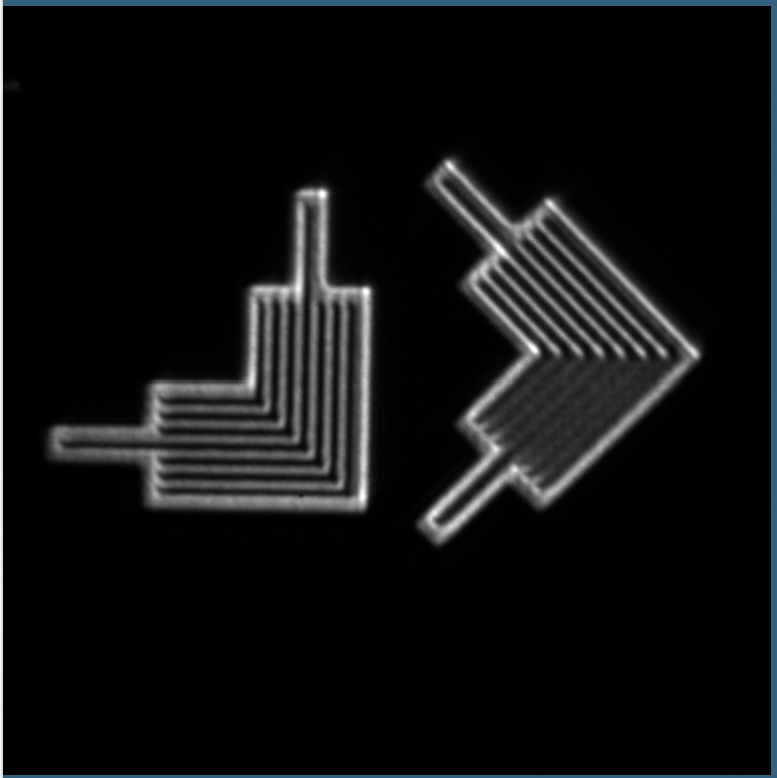
Elbows, 100-nm CD



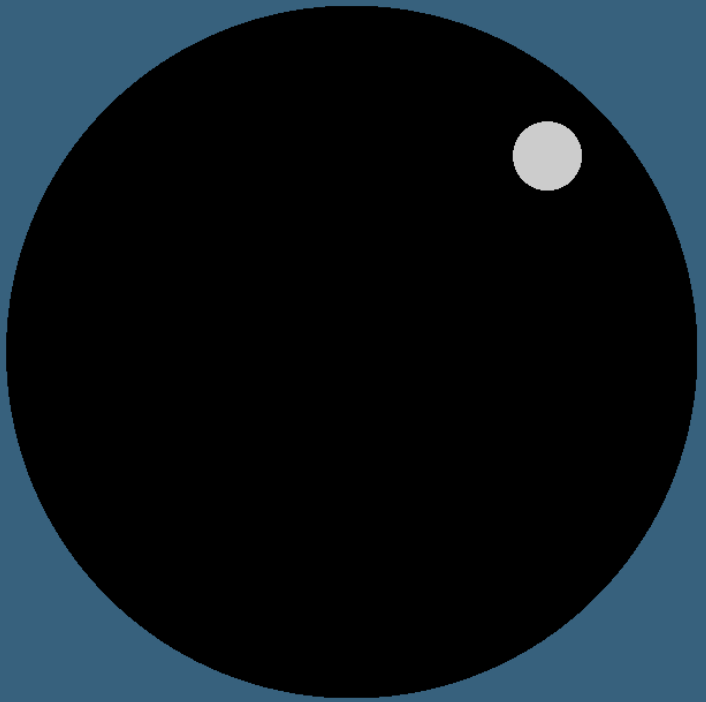
0.33 4xNA pupil

SHARP

Pupil-fill affects imaging



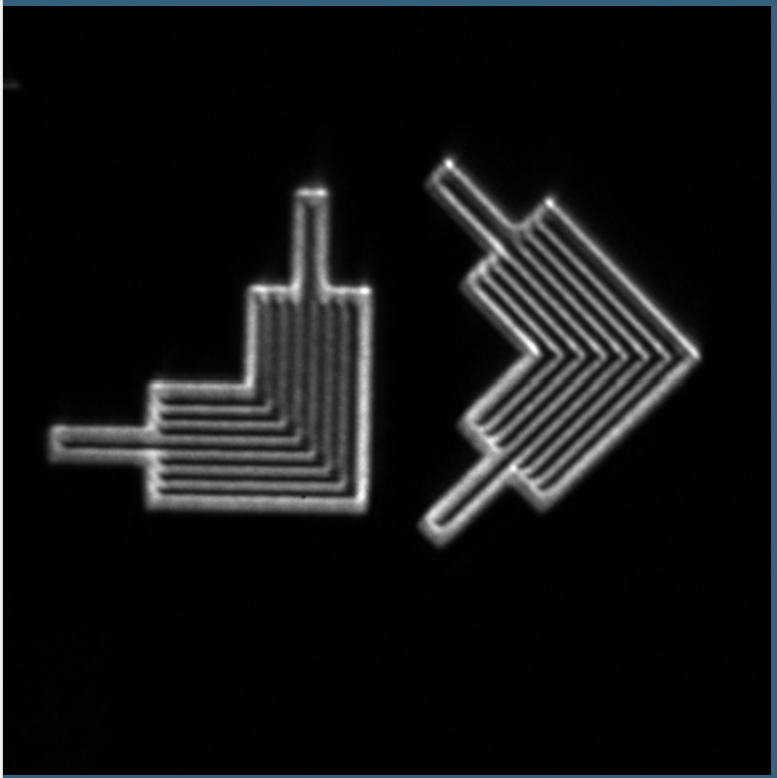
Elbows, 100-nm CD



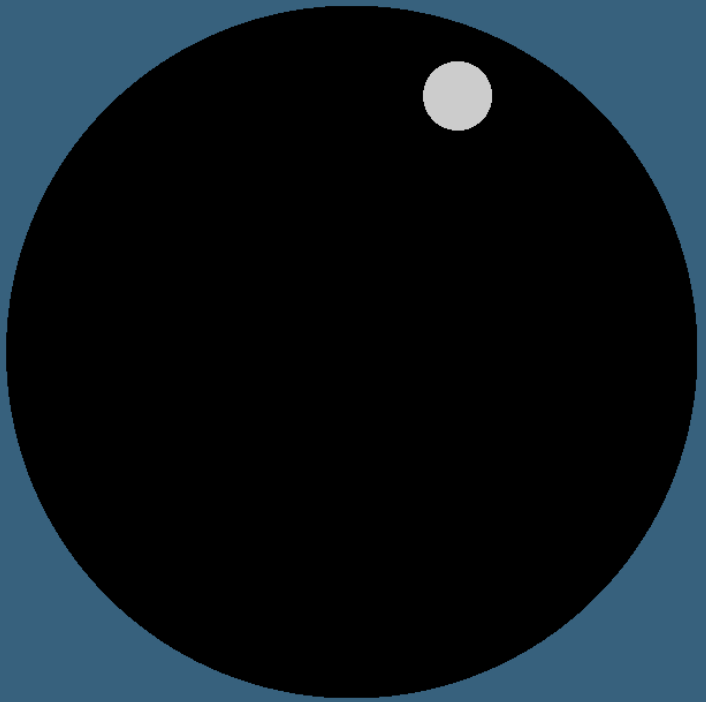
0.33 4xNA pupil

SHARP

Pupil-fill affects imaging



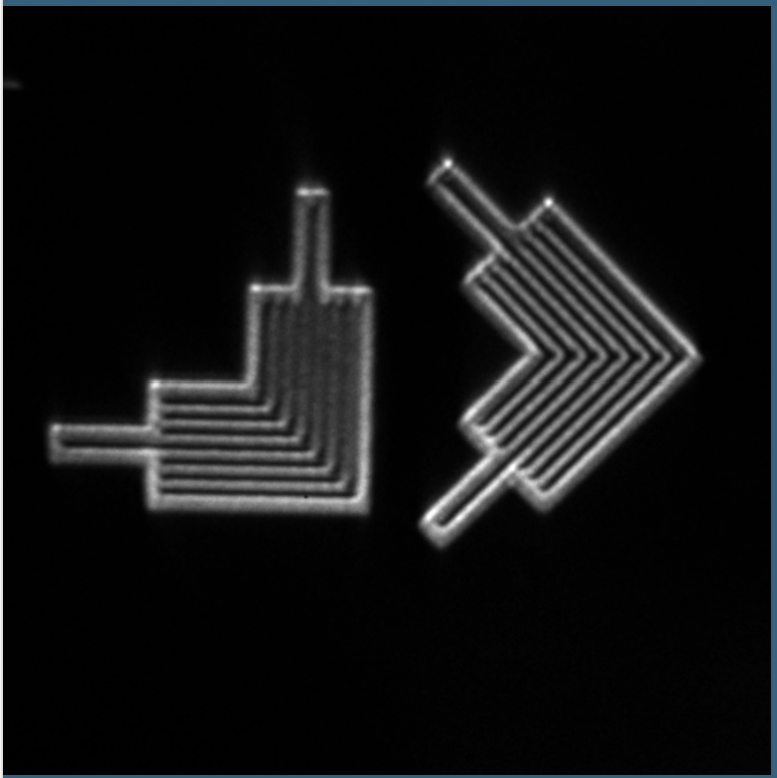
Elbows, 100-nm CD



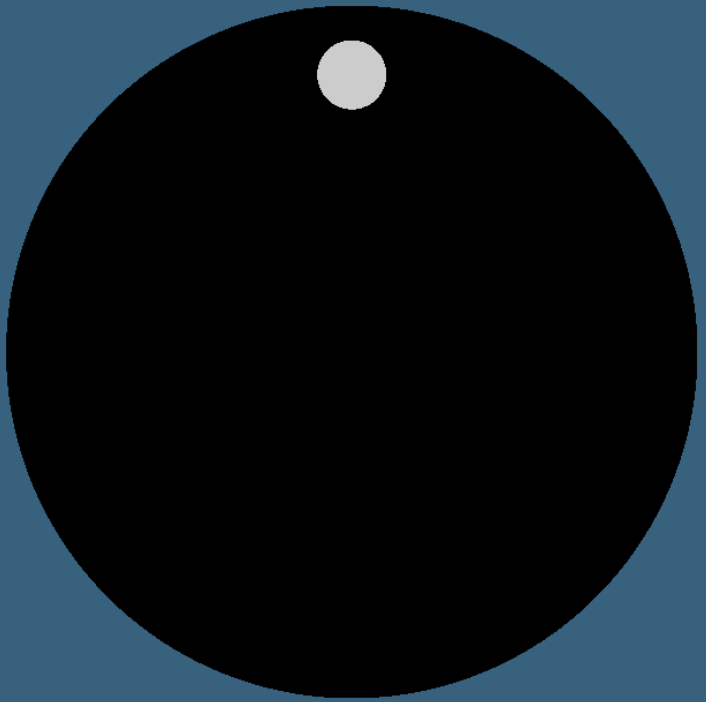
0.33 4xNA pupil

SHARP

Pupil-fill affects imaging



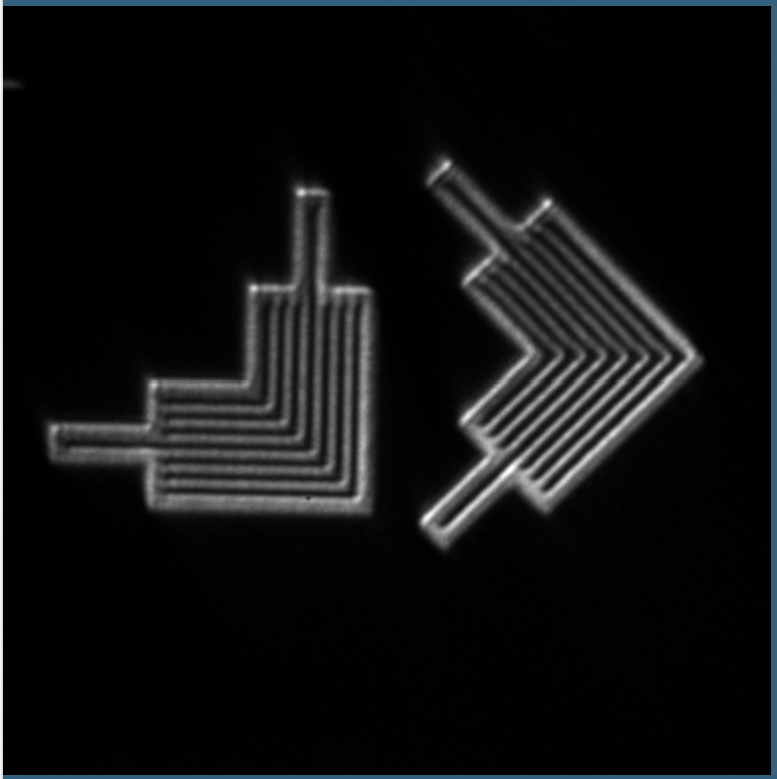
Elbows, 100-nm CD



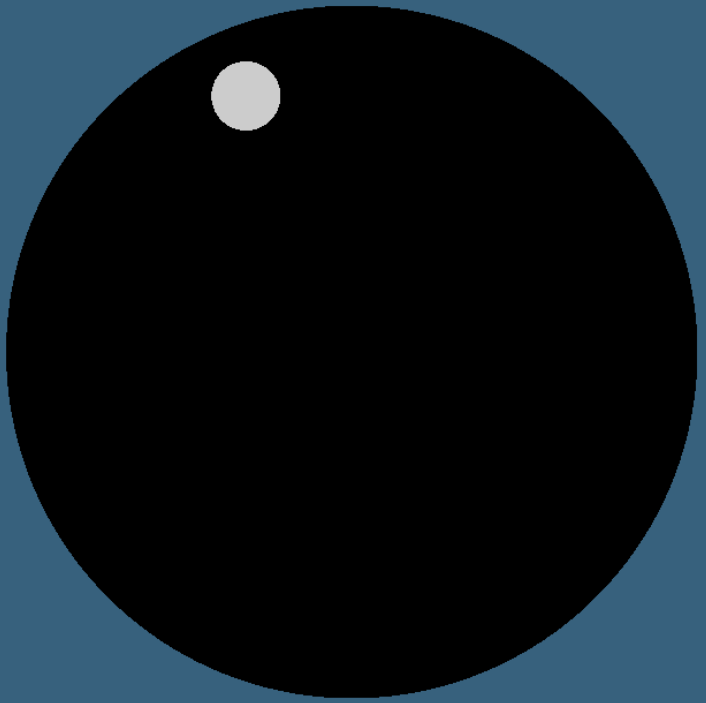
0.33 4xNA pupil

SHARP

Pupil-fill affects imaging



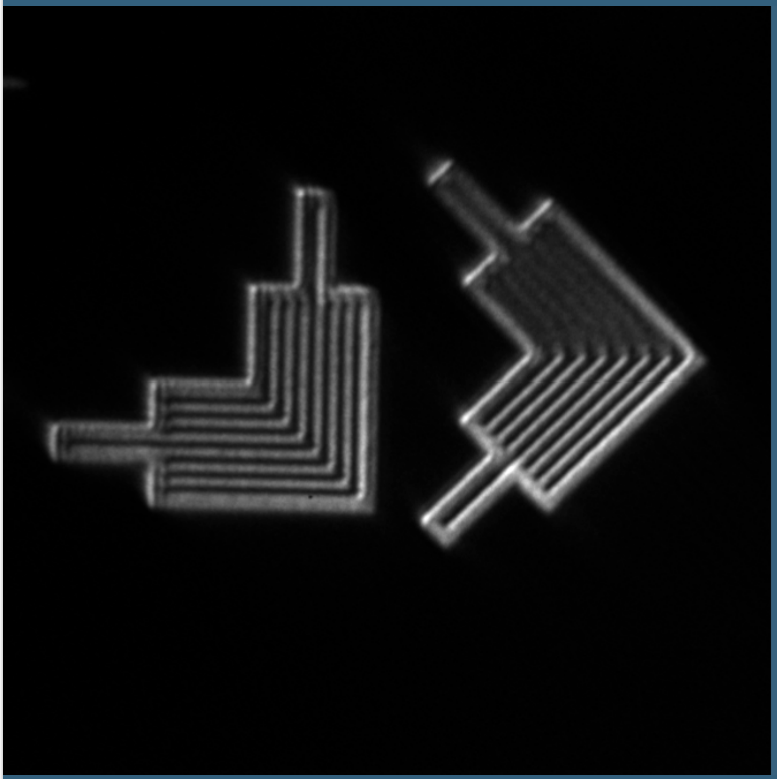
Elbows, 100-nm CD



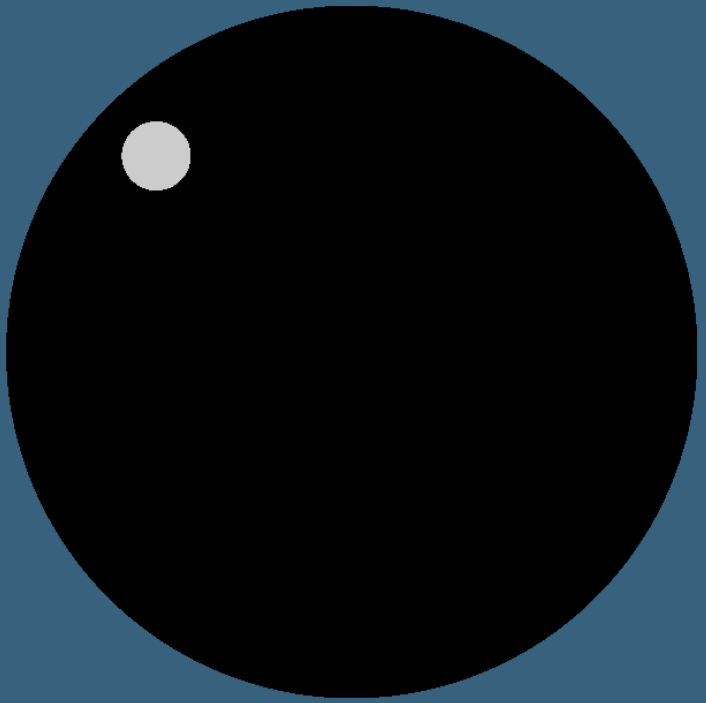
0.33 4xNA pupil

SHARP

Pupil-fill affects imaging



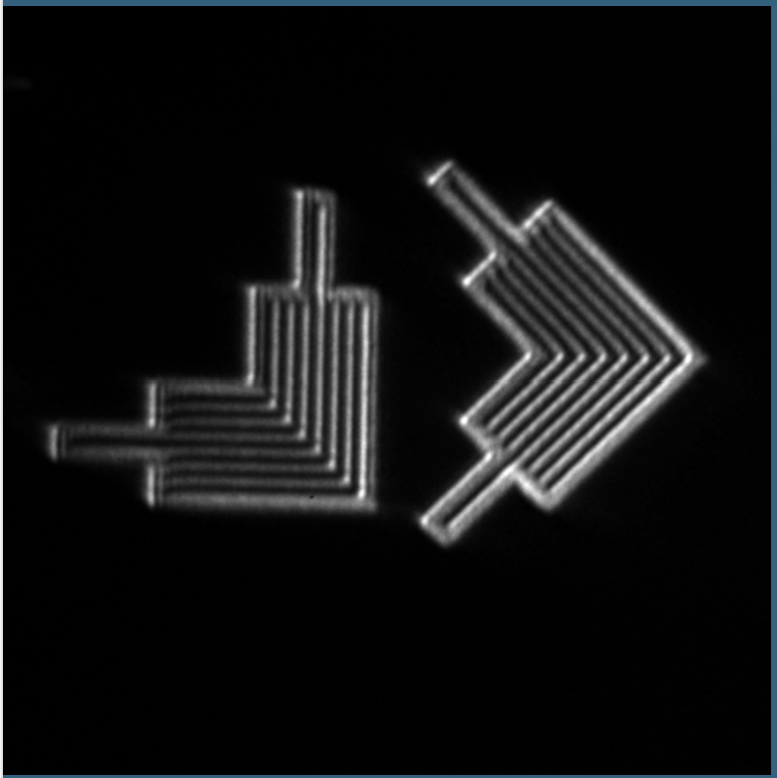
Elbows, 100-nm CD



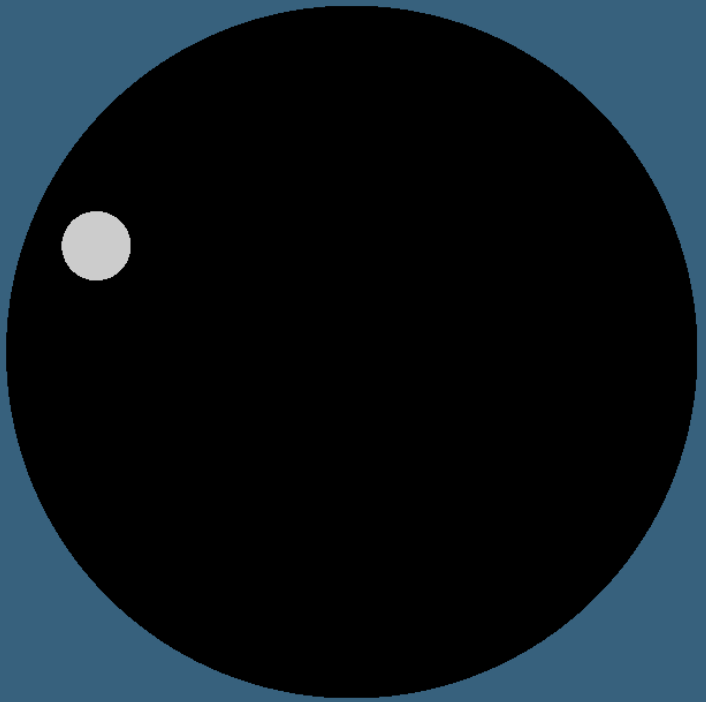
0.33 4xNA pupil

SHARP

Pupil-fill affects imaging



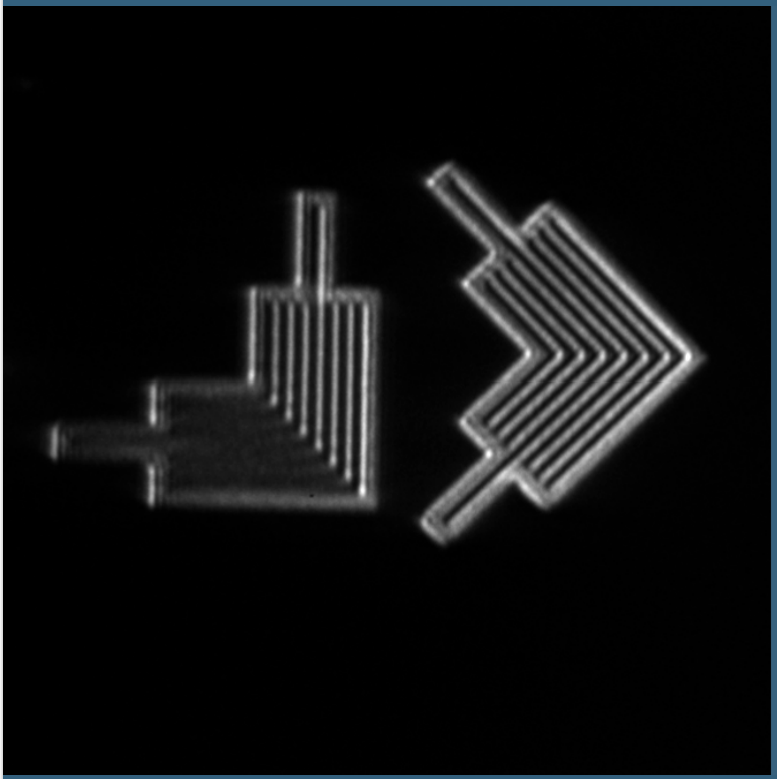
Elbows, 100-nm CD



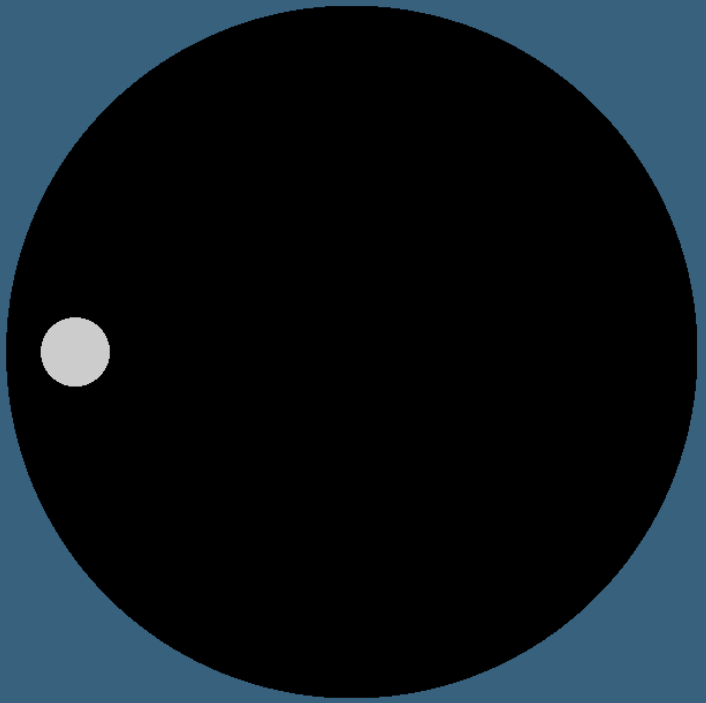
0.33 4xNA pupil

SHARP

Pupil-fill affects imaging



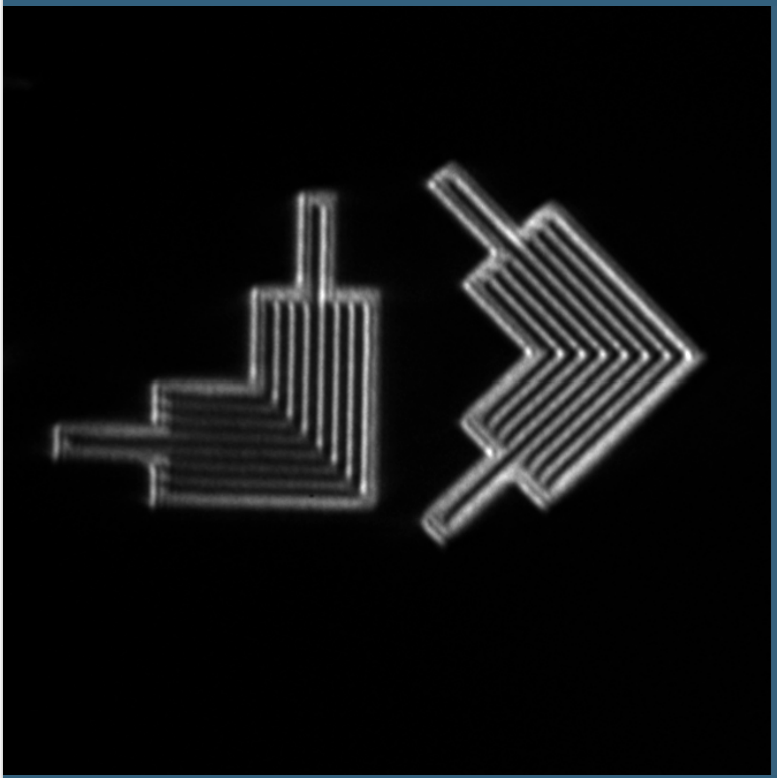
Elbows, 100-nm CD



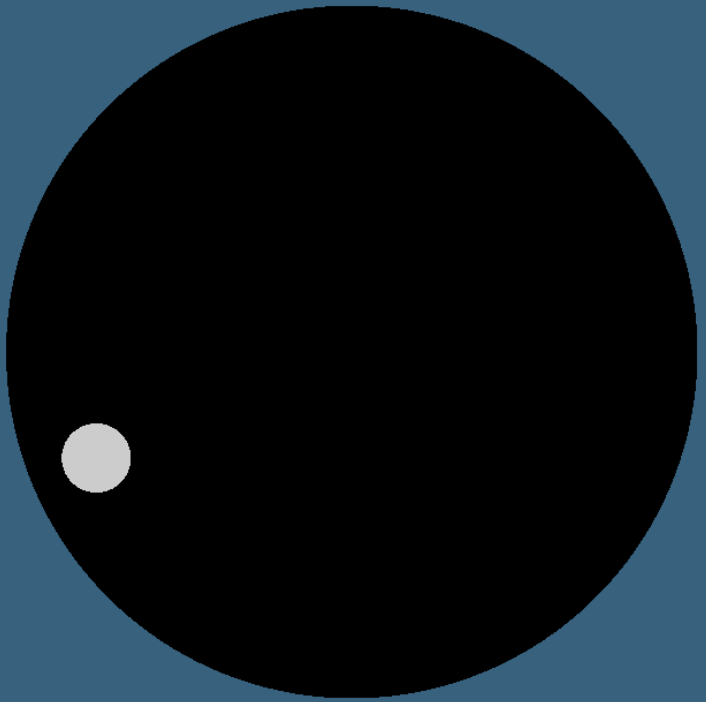
0.33 4xNA pupil

SHARP

Pupil-fill affects imaging



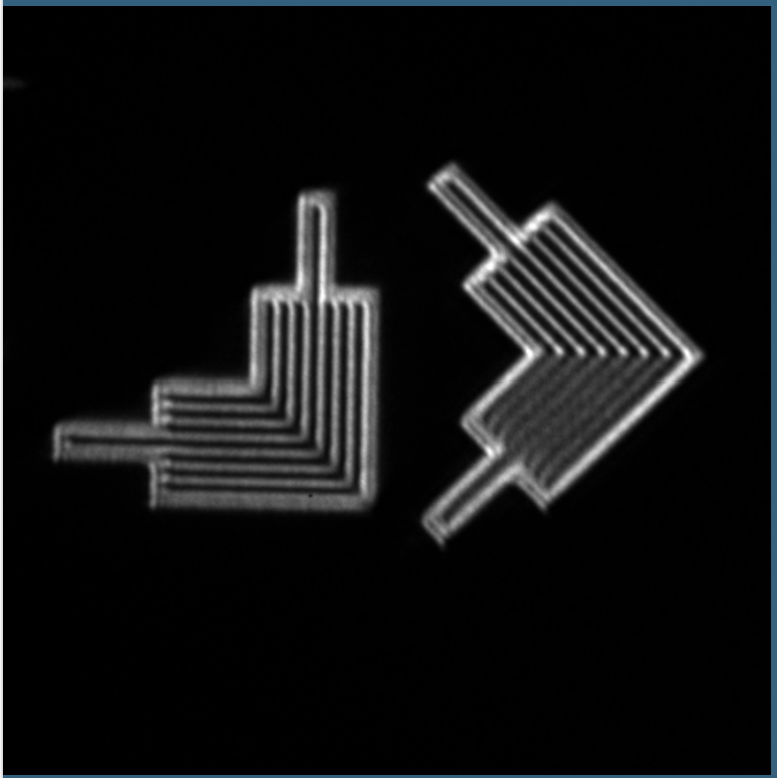
Elbows, 100-nm CD



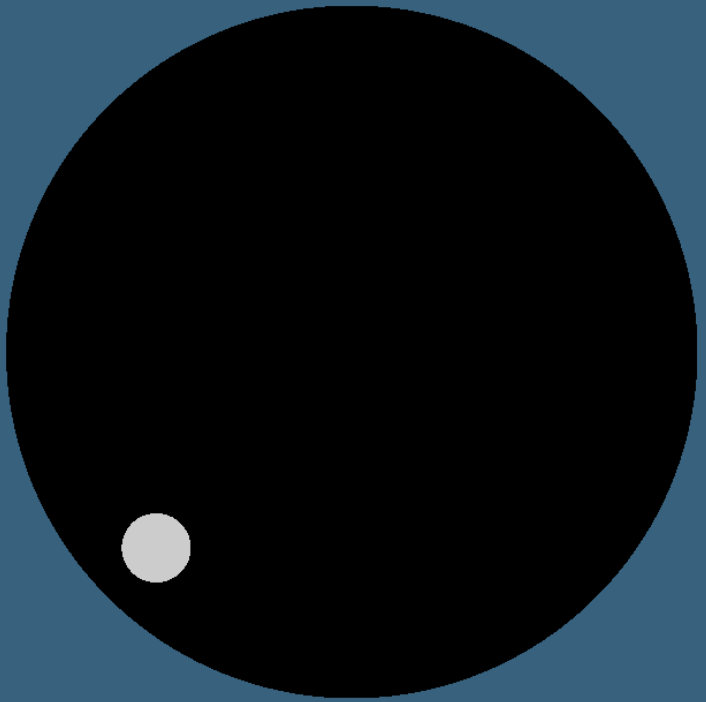
0.33 4xNA pupil

SHARP

Pupil-fill affects imaging

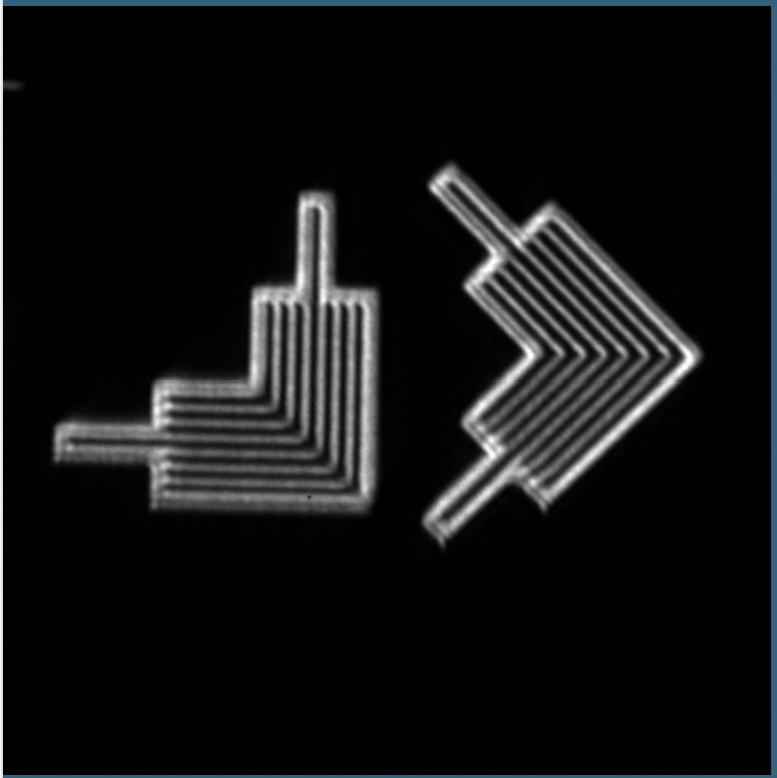


Elbows, 100-nm CD

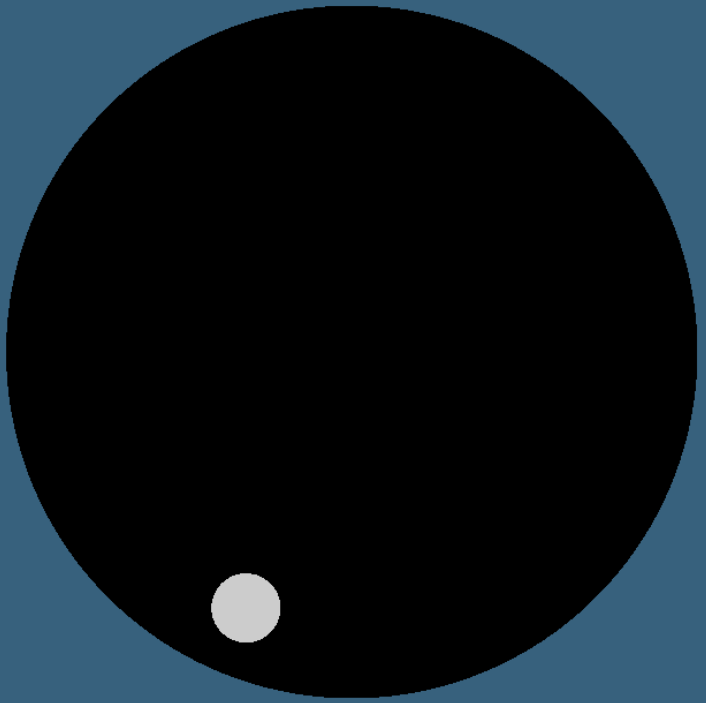


0.33 4xNA pupil

Pupil-fill affects imaging



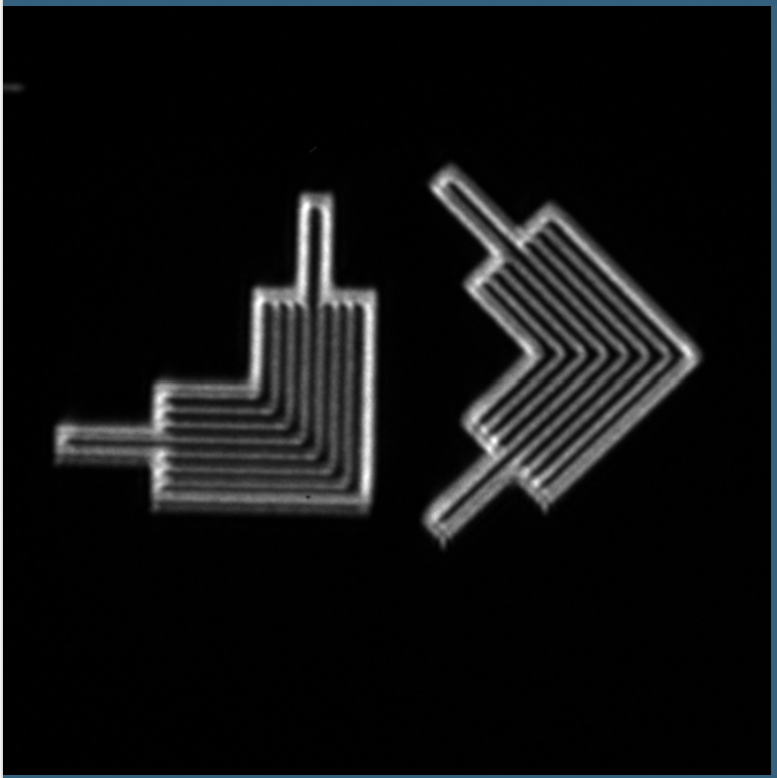
Elbows, 100-nm CD



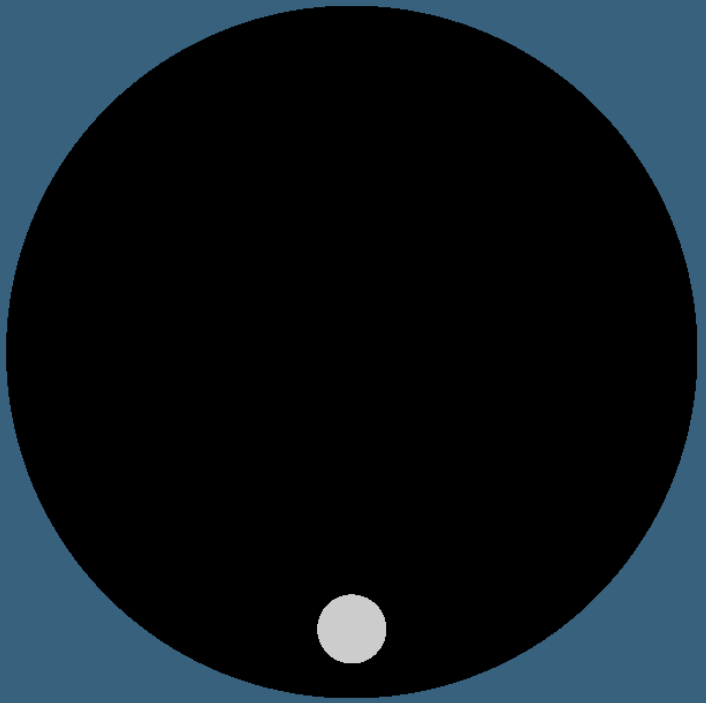
0.33 4xNA pupil

SHARP

Pupil-fill affects imaging



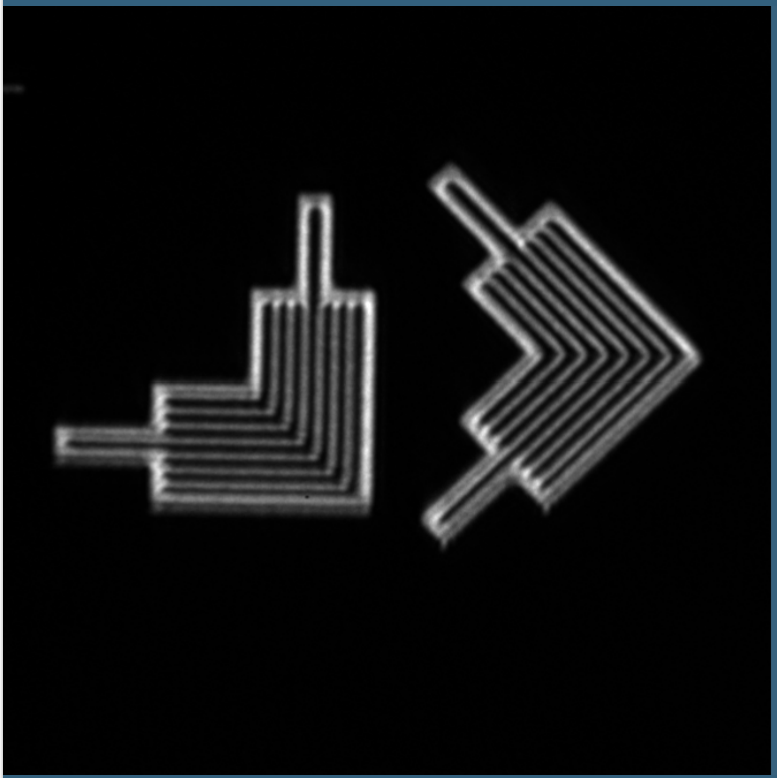
Elbows, 100-nm CD



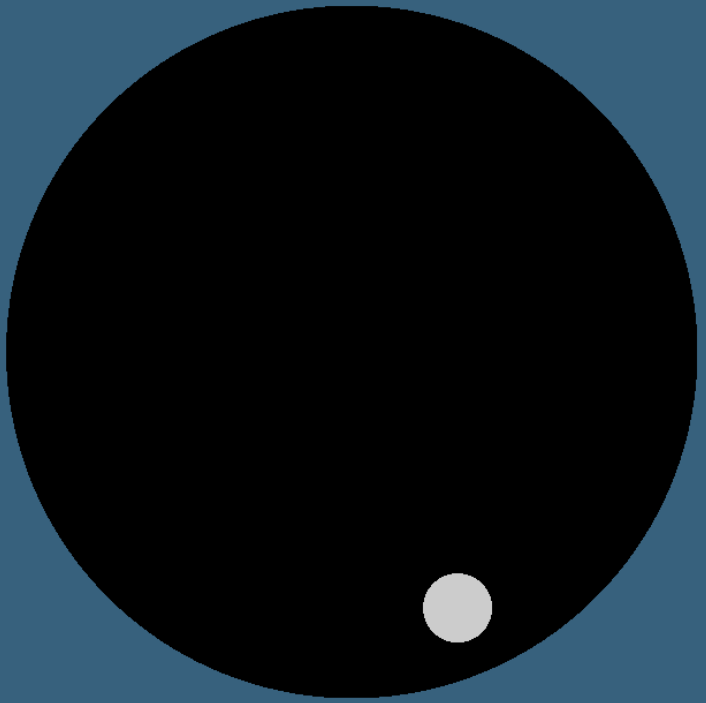
0.33 4xNA pupil

SHARP

Pupil-fill affects imaging



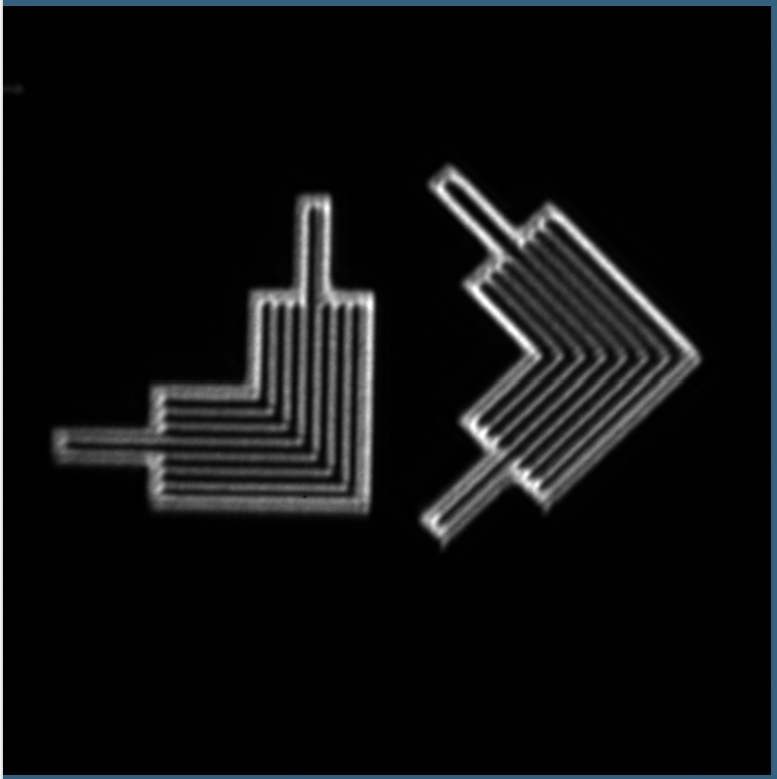
Elbows, 100-nm CD



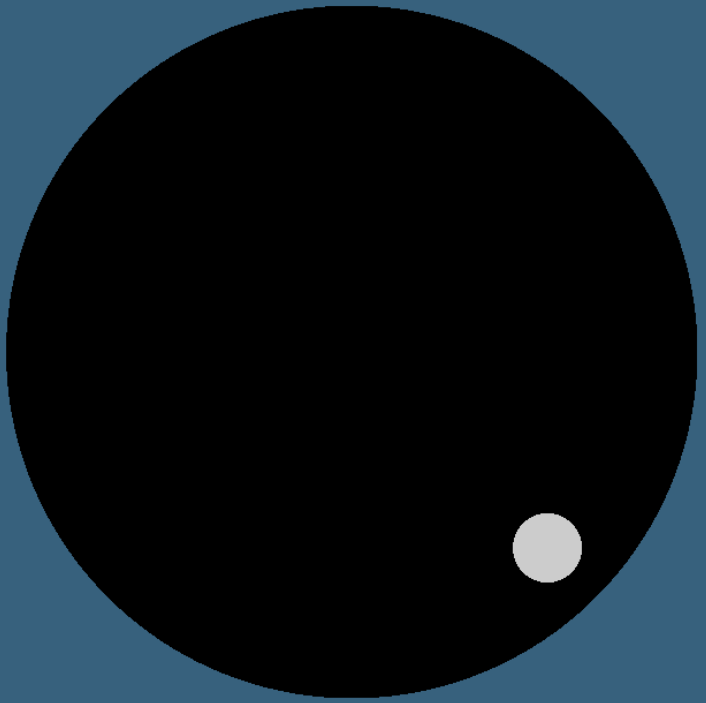
0.33 4xNA pupil

SHARP

Pupil-fill affects imaging



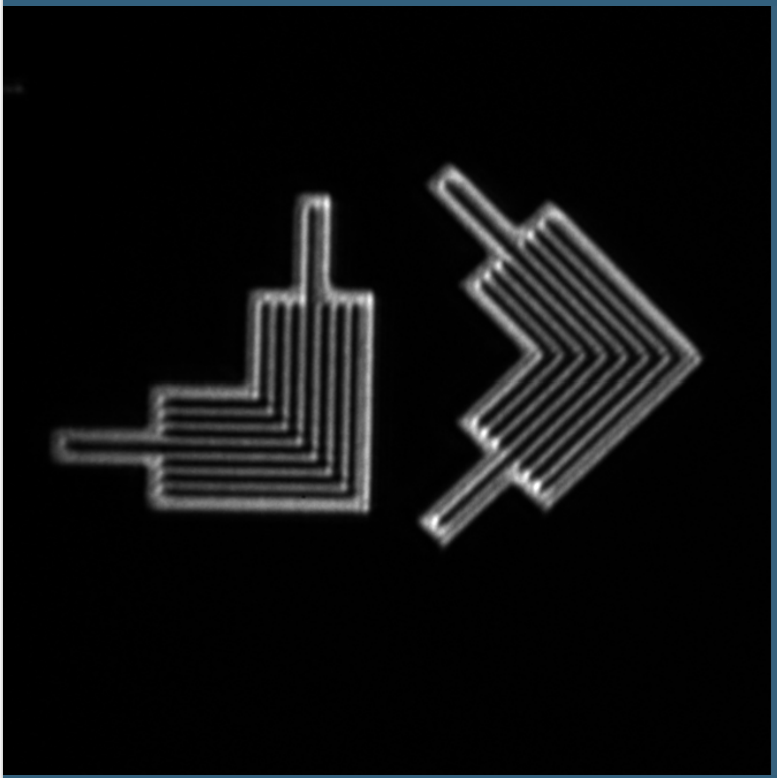
Elbows, 100-nm CD



0.33 4xNA pupil

SHARP

Pupil-fill affects imaging

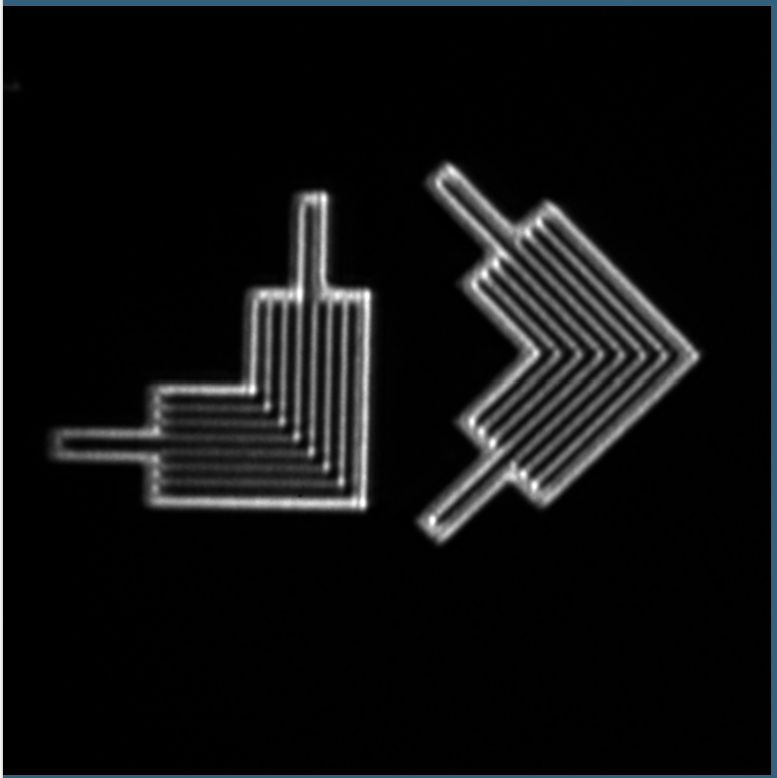


Elbows, 100-nm CD

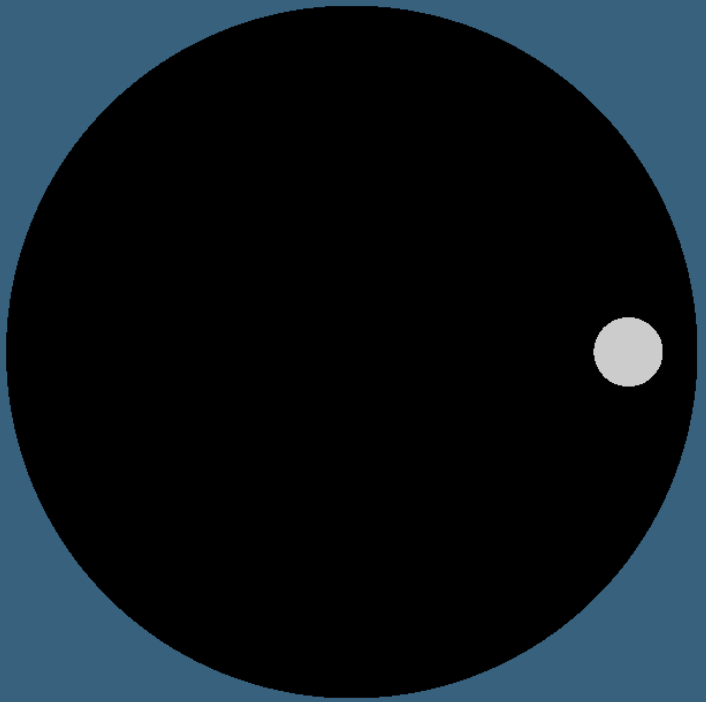
0.33 4xNA pupil

SHARP

Pupil-fill affects imaging



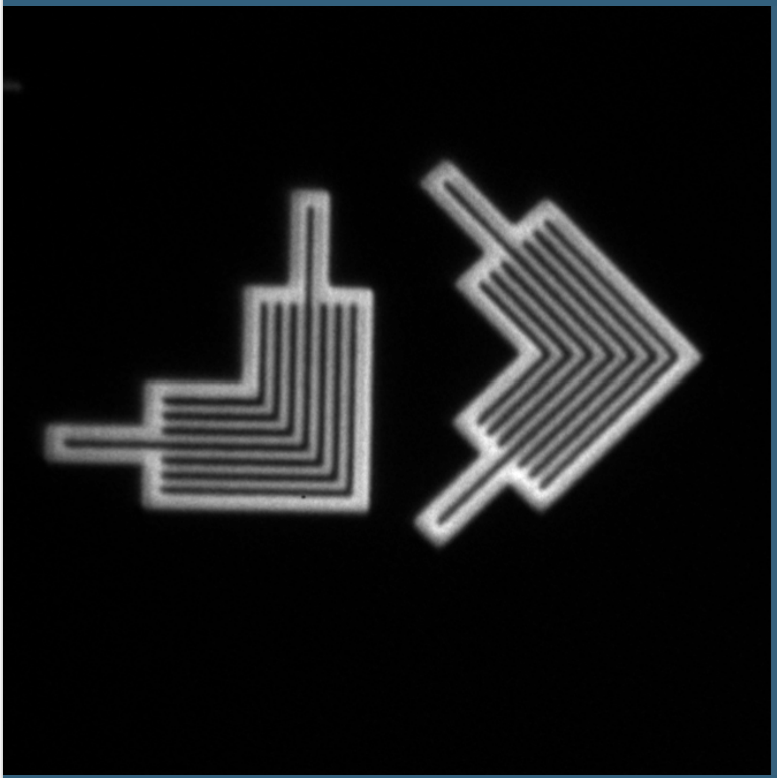
Elbows, 100-nm CD



0.33 4xNA pupil

SHARP

Pupil-fill affects imaging

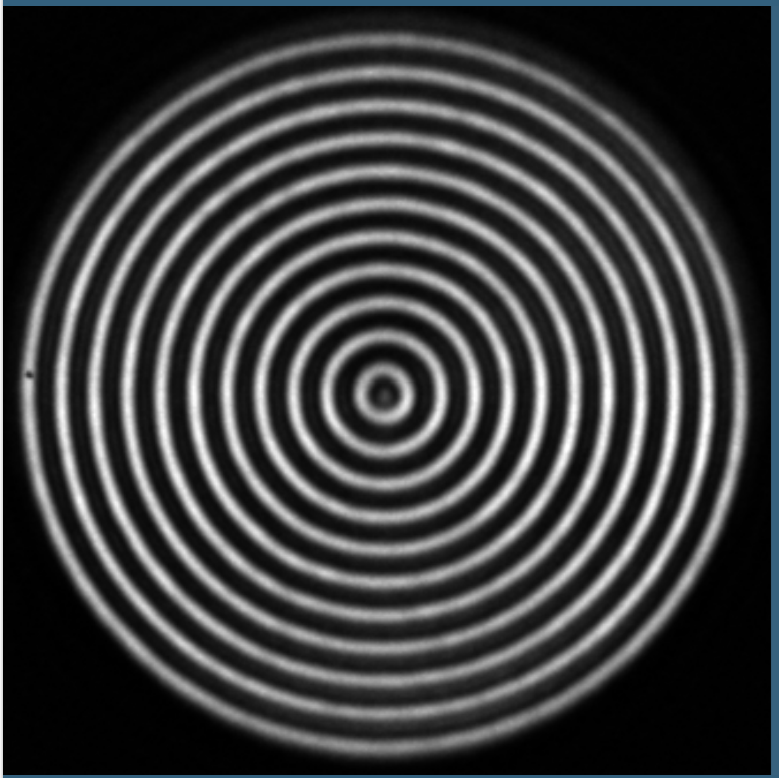


Elbows, 100-nm CD

0.33 4xNA pupil

SHARP

Coherence affects imaging



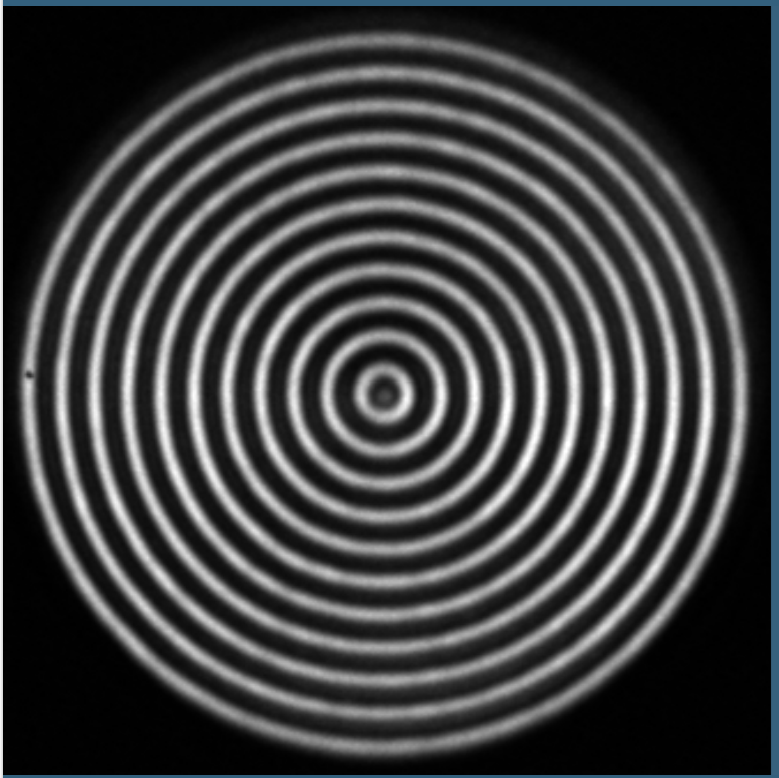
Circles, 110-nm CD

0.33 4xNA pupil

σ = 0.1

SHARP

Coherence affects imaging



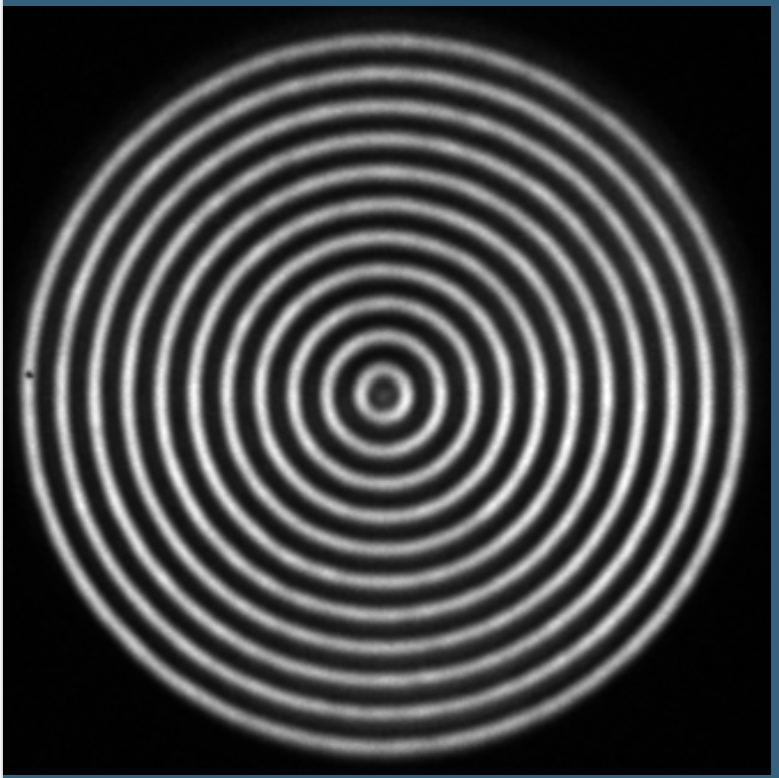
Circles, 110-nm CD

0.33 4xNA pupil

$\sigma = 0.2$

SHARP

Coherence affects imaging



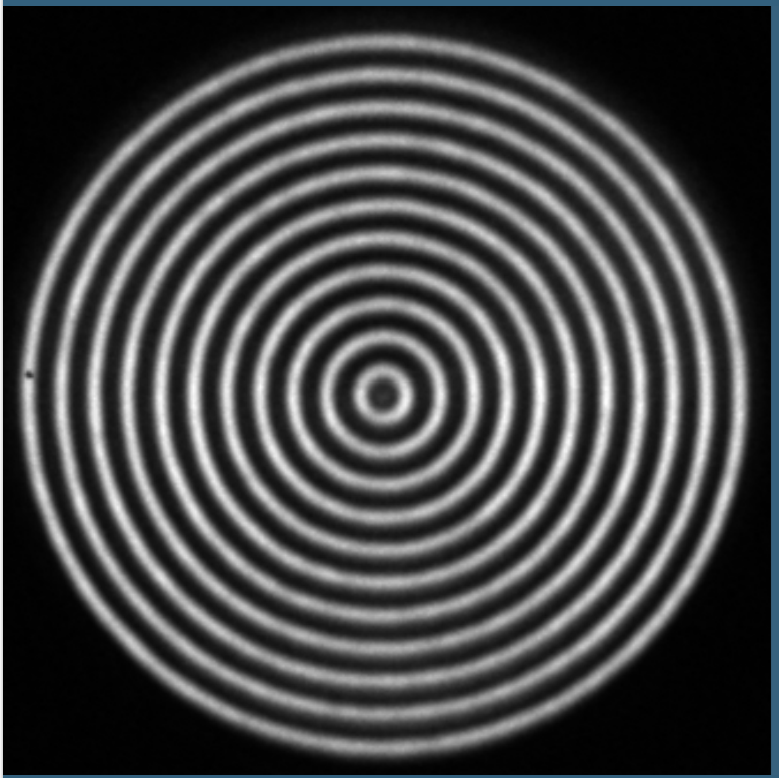
Circles, 110-nm CD

0.33 4xNA pupil

$\sigma = 0.3$

SHARP

Coherence affects imaging



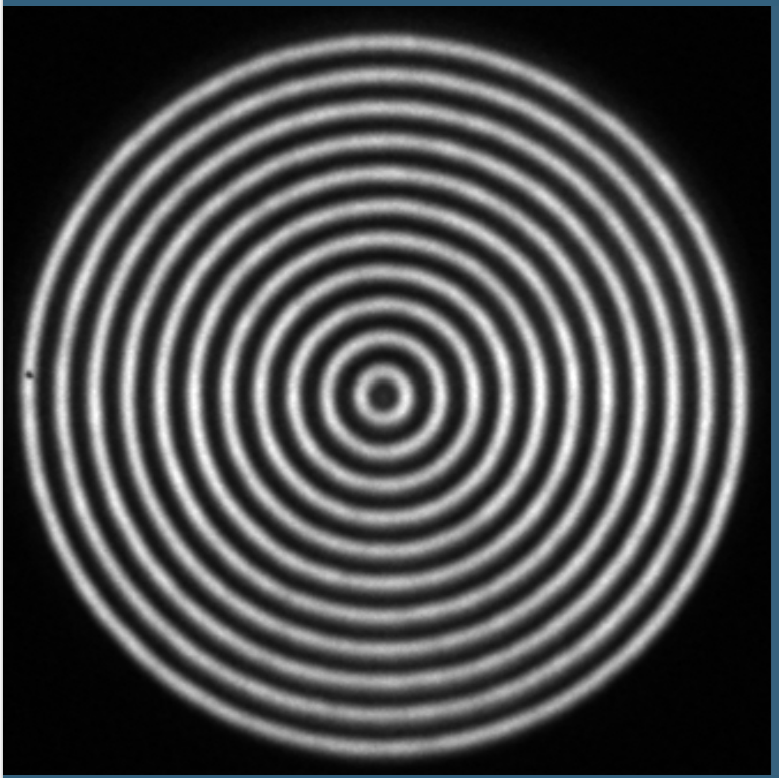
Circles, 110-nm CD

0.33 4xNA pupil

$\sigma = 0.4$

SHARP

Coherence affects imaging



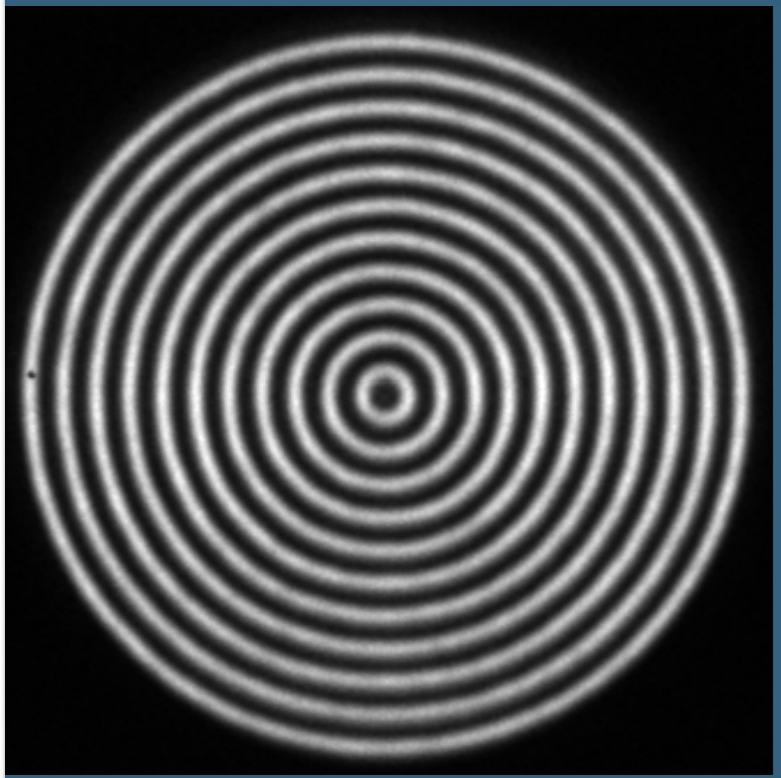
Circles, 110-nm CD

0.33 4xNA pupil

$\sigma = 0.5$

SHARP

Coherence affects imaging



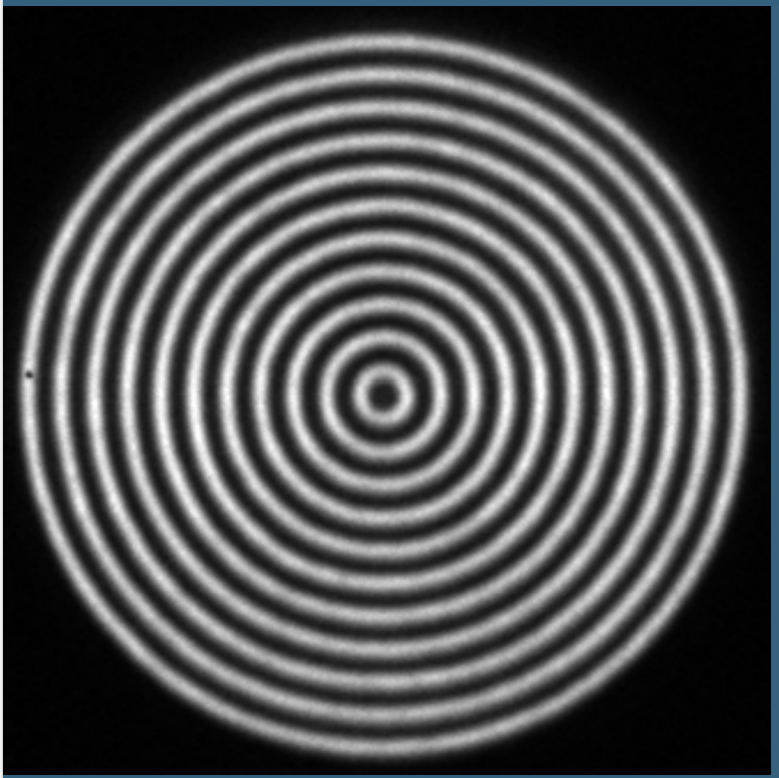
Circles, 110-nm CD

0.33 4xNA pupil

$\sigma = 0.6$

SHARP

Coherence affects imaging



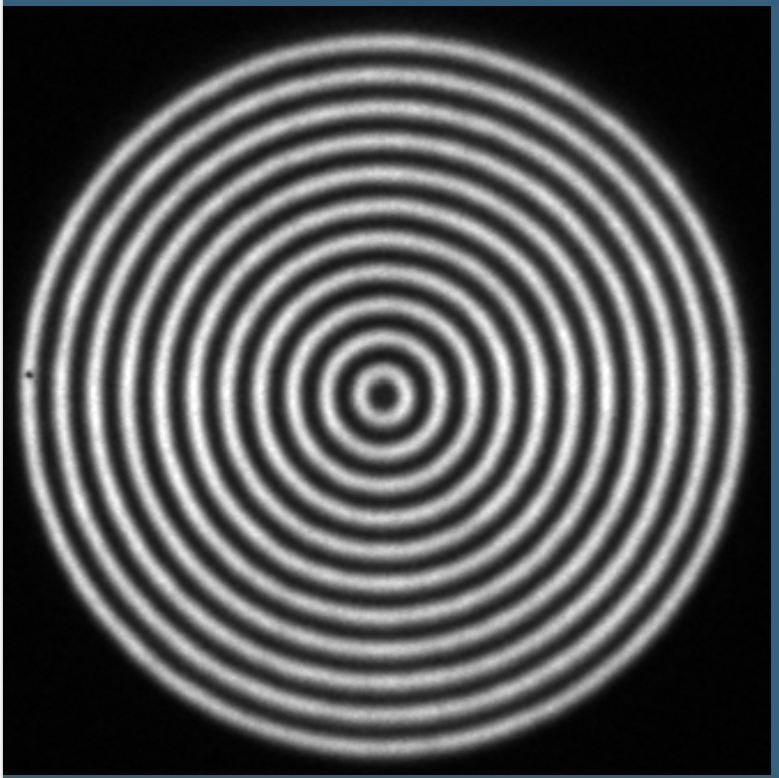
Circles, 110-nm CD

0.33 4xNA pupil

$\sigma = 0.7$

SHARP

Coherence affects imaging



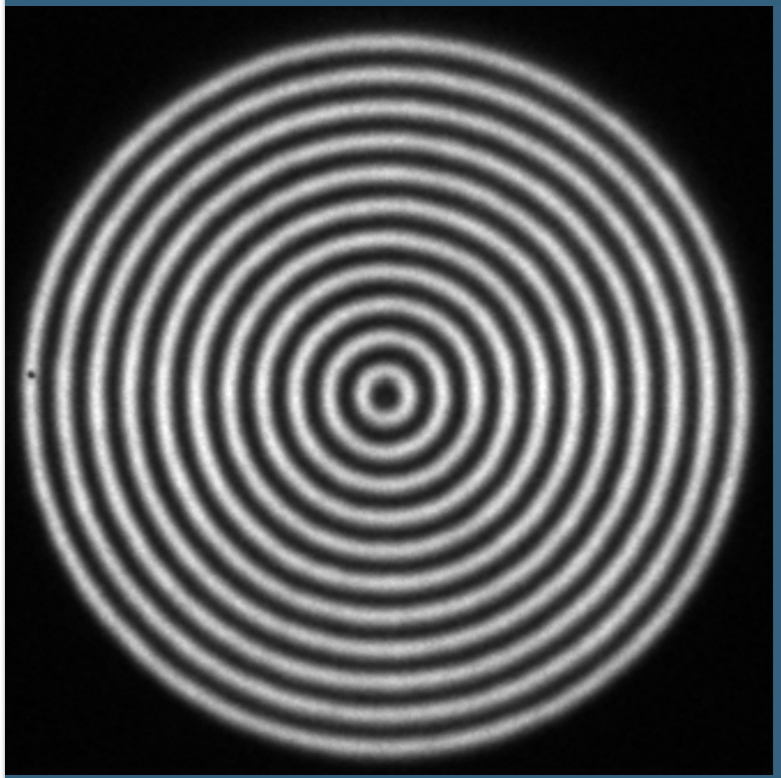
Circles, 110-nm CD

0.33 4xNA pupil

$\sigma = 0.8$

SHARP

Coherence affects imaging



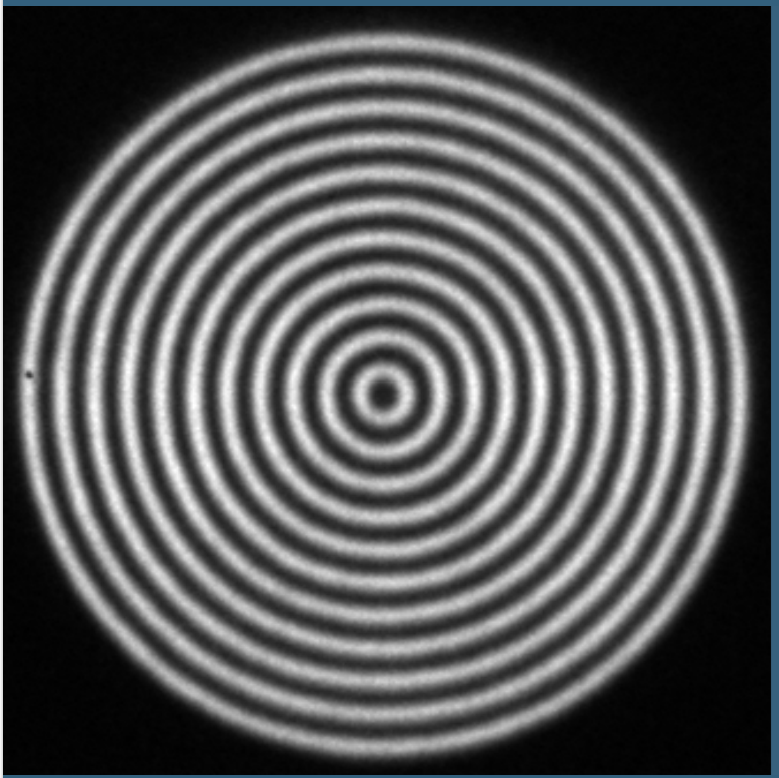
Circles, 110-nm CD

0.33 4xNA pupil

$\sigma = 0.9$

SHARP

Coherence affects imaging



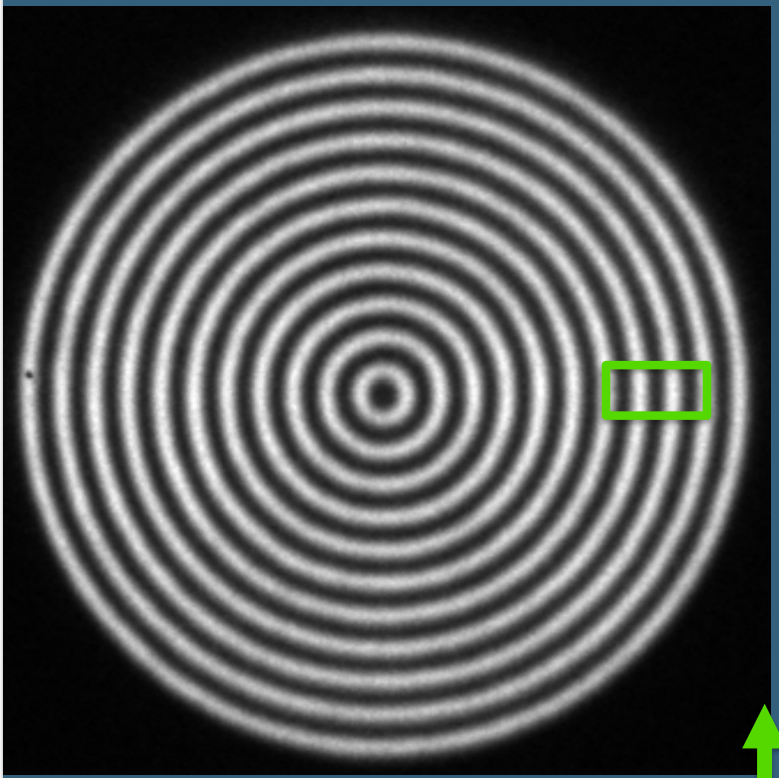
Circles, 110-nm CD

0.33 4xNA pupil

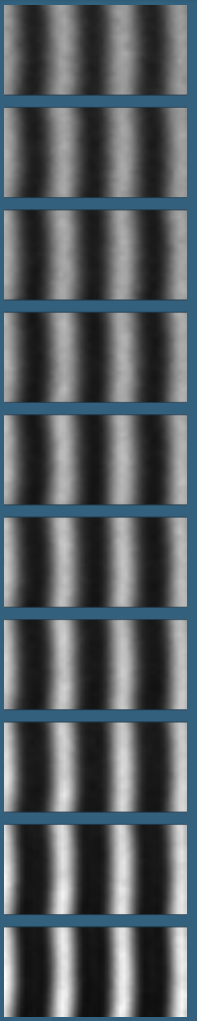
σ = 1.0

SHARP

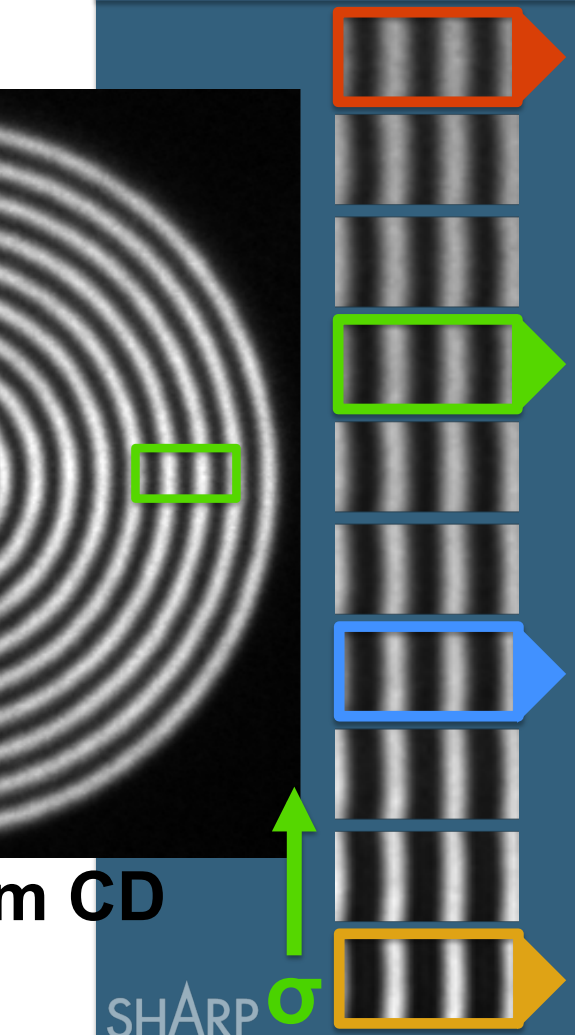
Coherence affects imaging

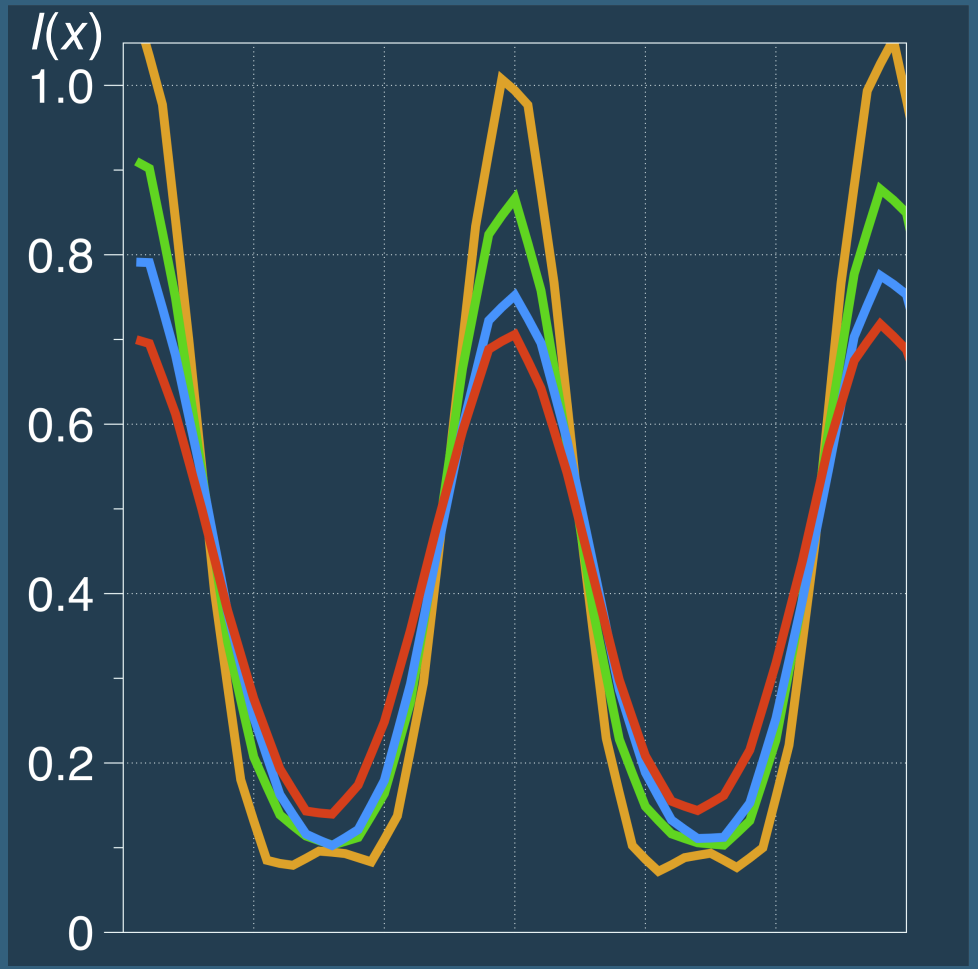


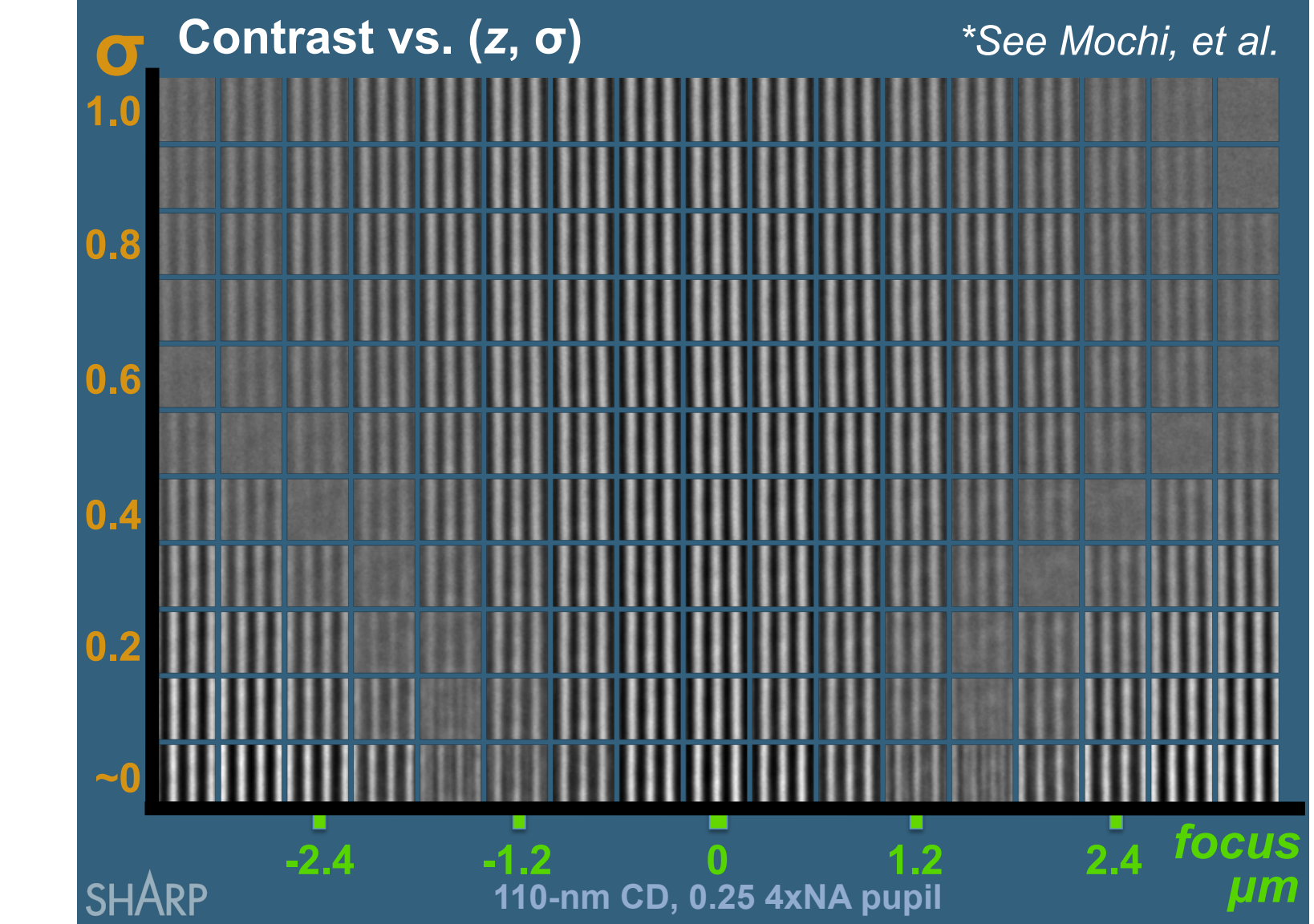
Circles, 110-nm CD

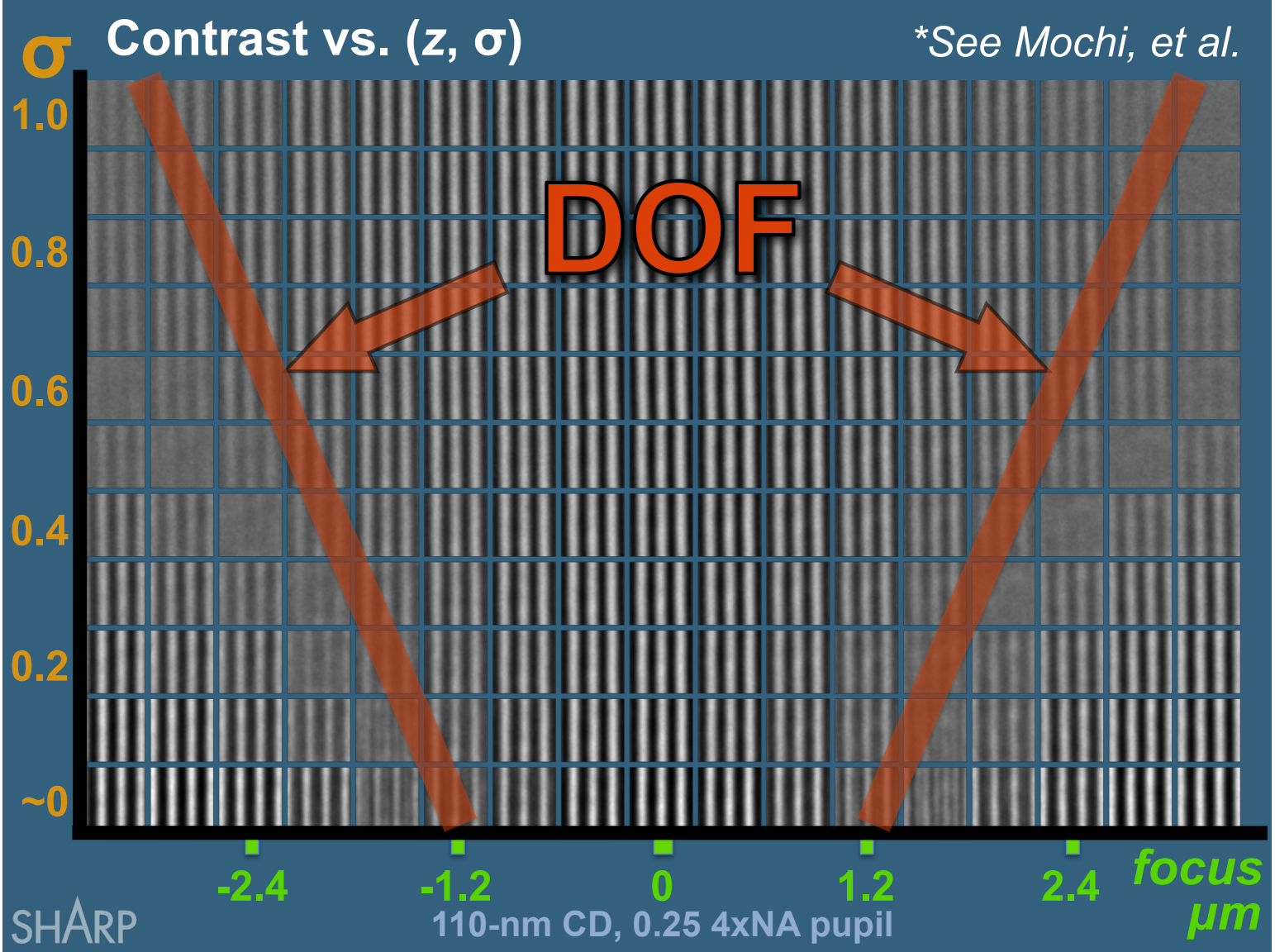


Coherence affects imaging






Contrast vs. (z, σ)
*See Mochi, et al.
σ
1.0
0.8
0.6
0.4
0.2
~0
-2.4
-1.2
0
1.2
2.4
focus
μm
SHARP
110-nm CD, 0.25 4xNA pupil

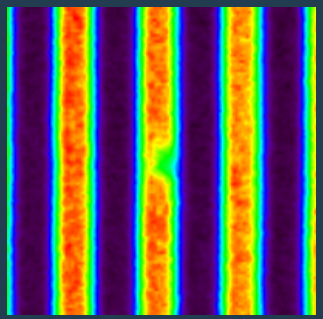

Contrast vs. (z, σ)
*See Mochi, et al.
σ
1.0
0.8
0.6
0.4
0.2
~0
DOF
-2.4
-1.2
0
1.2
2.4
focus
μm
SHARP
110-nm CD, 0.25 4xNA pupil

Native defect, illumination studies

Gremlin3, Defect 1439, 200 nm hp

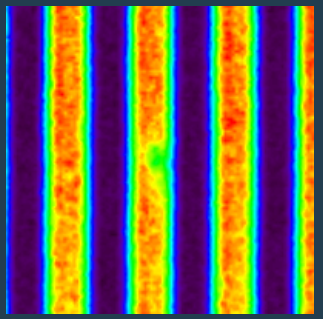
Mask/KLA617 Teron

Quasar 45° illumination



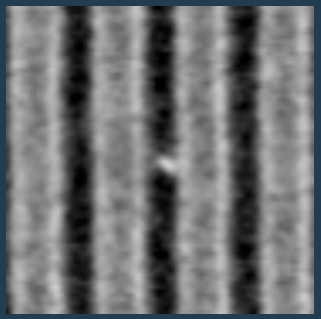
GREMLIN3-130709-0031

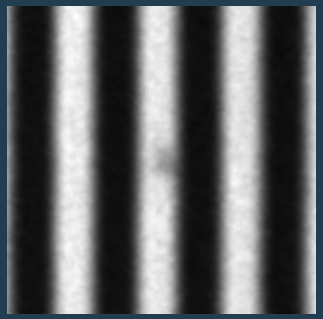
Annular illumination

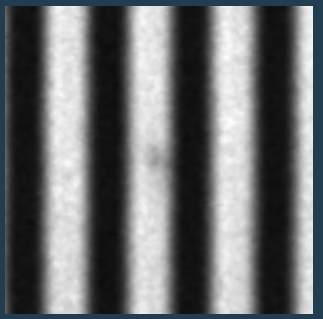


GREMLIN3-130709-0032

Mask/SEM







1.5 µm

SHARP

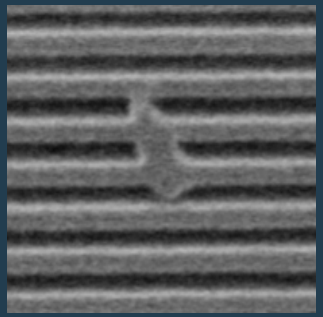
GLOBALFOUNDRIES

Native defect, illumination studies

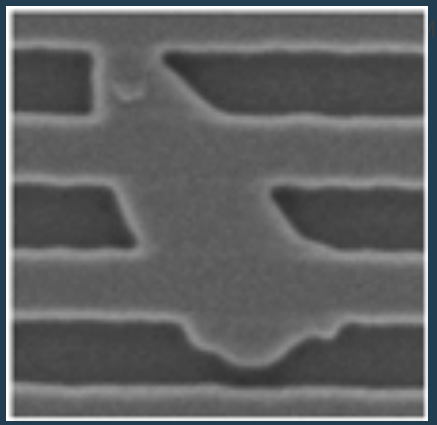
Gremlin3, Defect 3200, 110 nm hp

Mask/KLA617
Teron

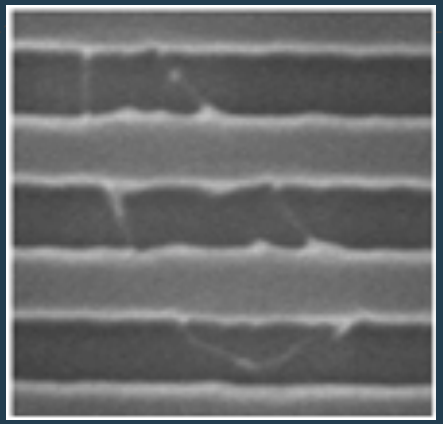
Mask/SEM



Pre-Repair



Post-Repair

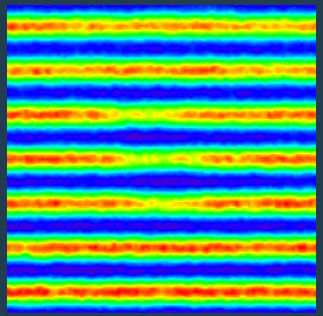
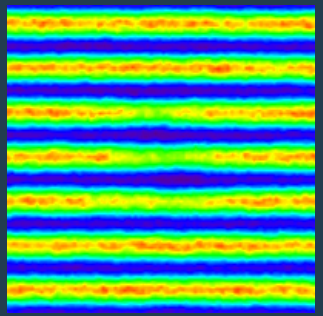
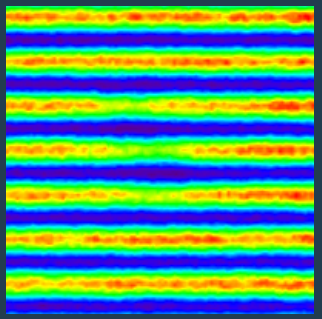
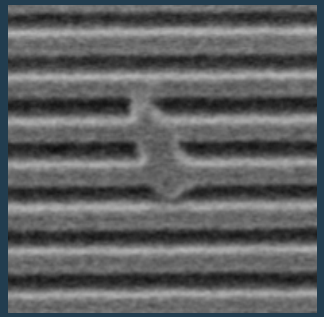
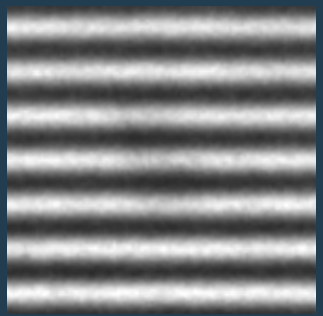
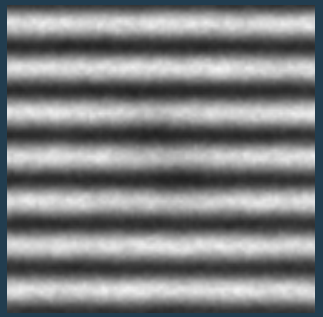
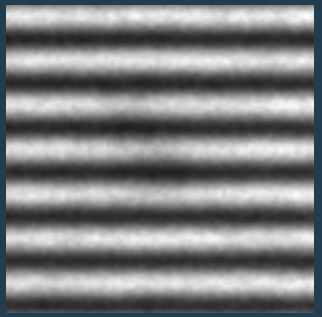


SHARP

GLOBALFOUNDRIES

Native defect, illumination studies

Gremlin3, Defect 3200, 110 nm hp

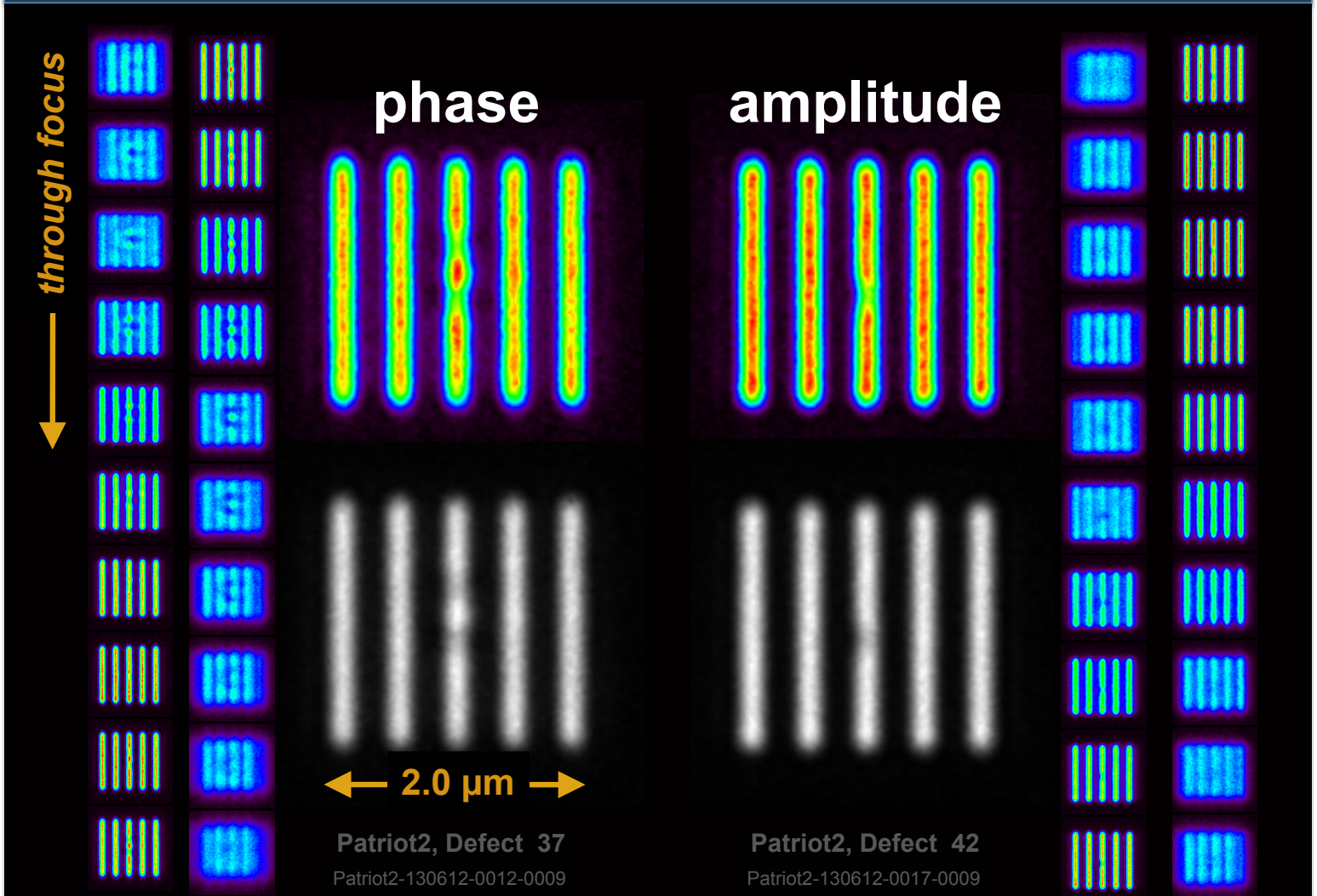
Mask/KLA617 Teron	Disk 0.9 σ illumination	Annular illumination	Quasar 45° illumination
			
	GREMLIN3-130709-0012	GREMLIN3-130709-0029	GREMLIN3-130709-0030
Mask/SEM			
			

1.5 µm

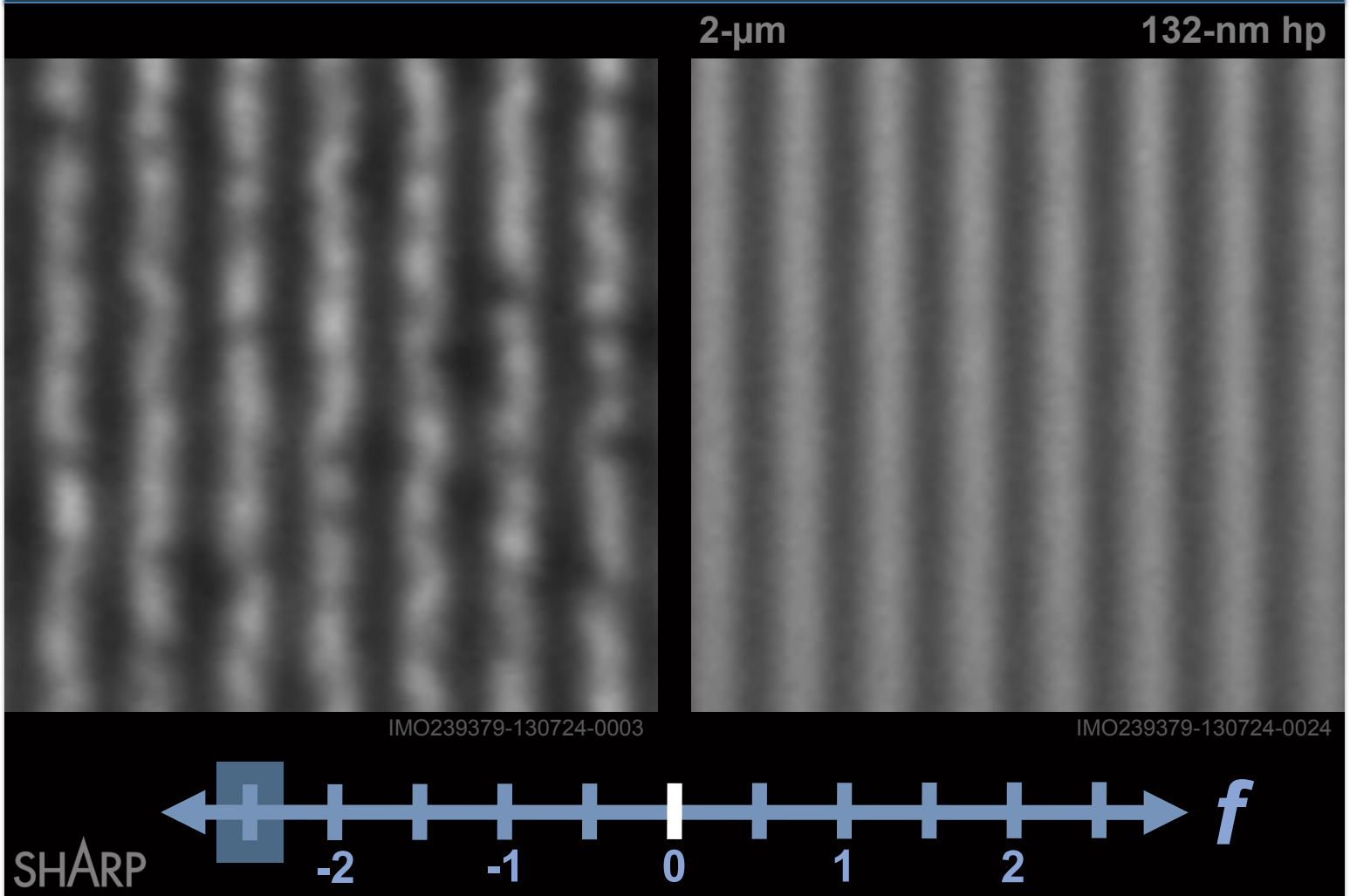
SHARP

GLOBALFOUNDRIES

Native phase and amplitude defects



Substrate roughness experiments



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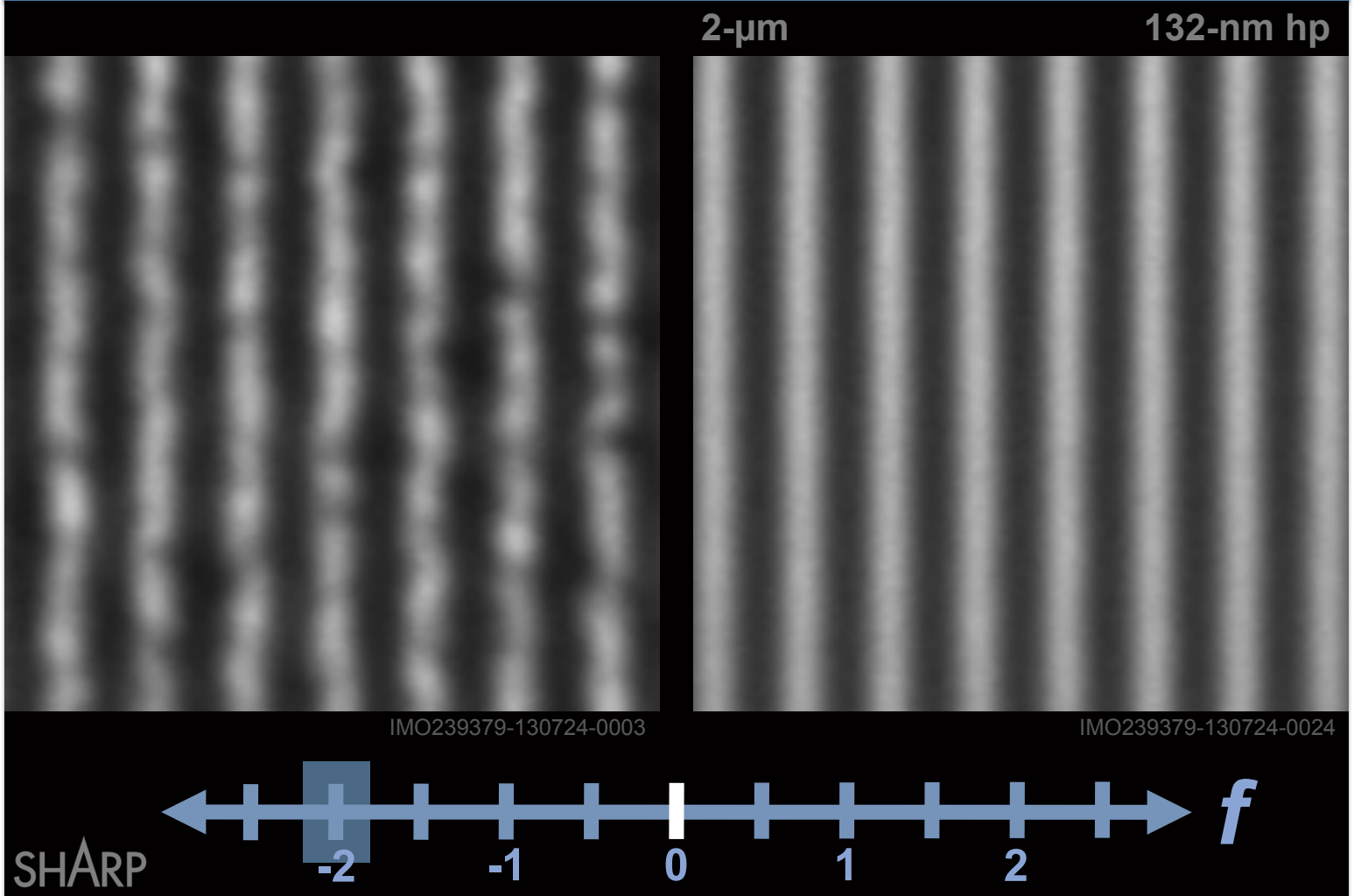

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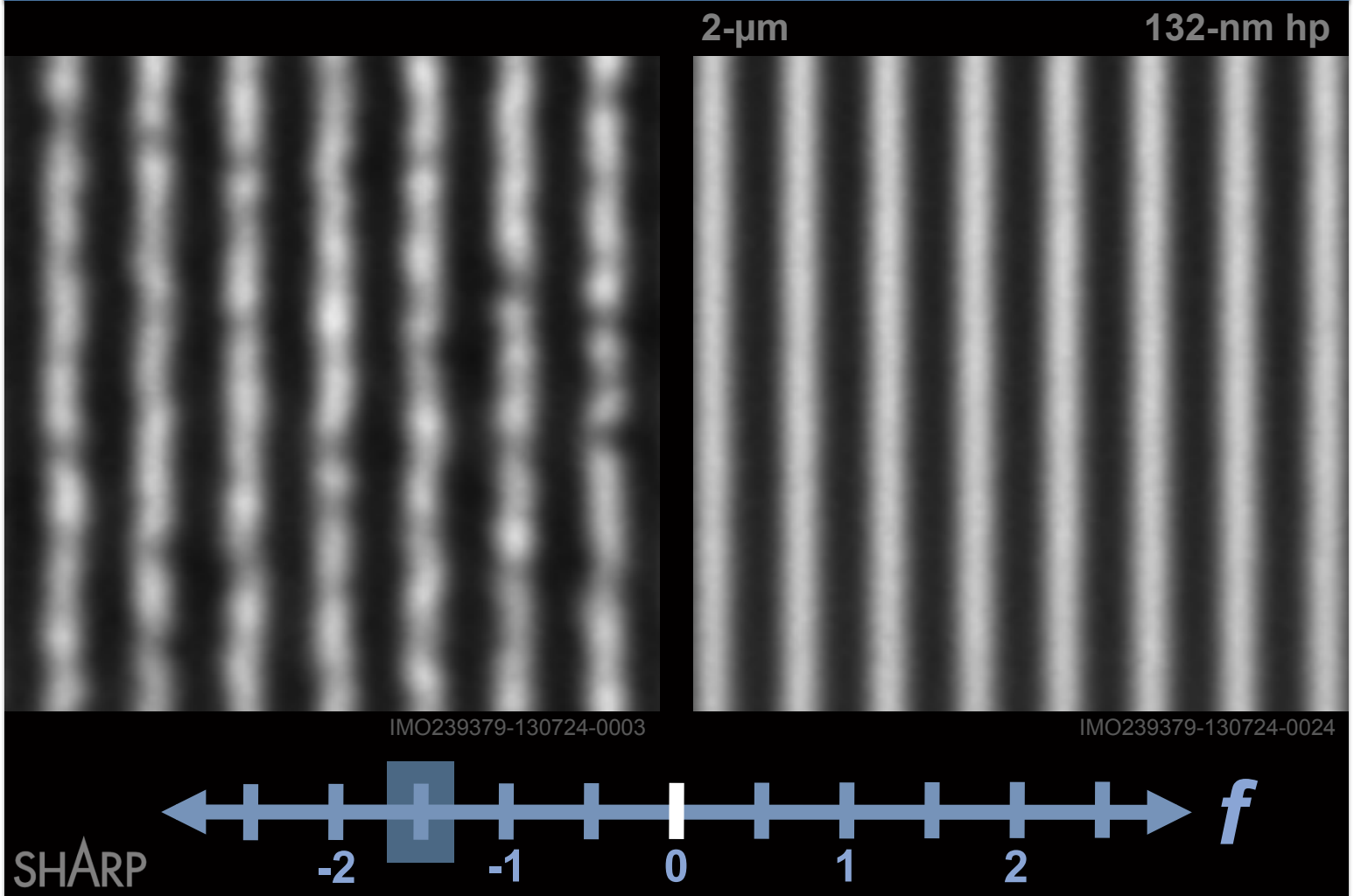

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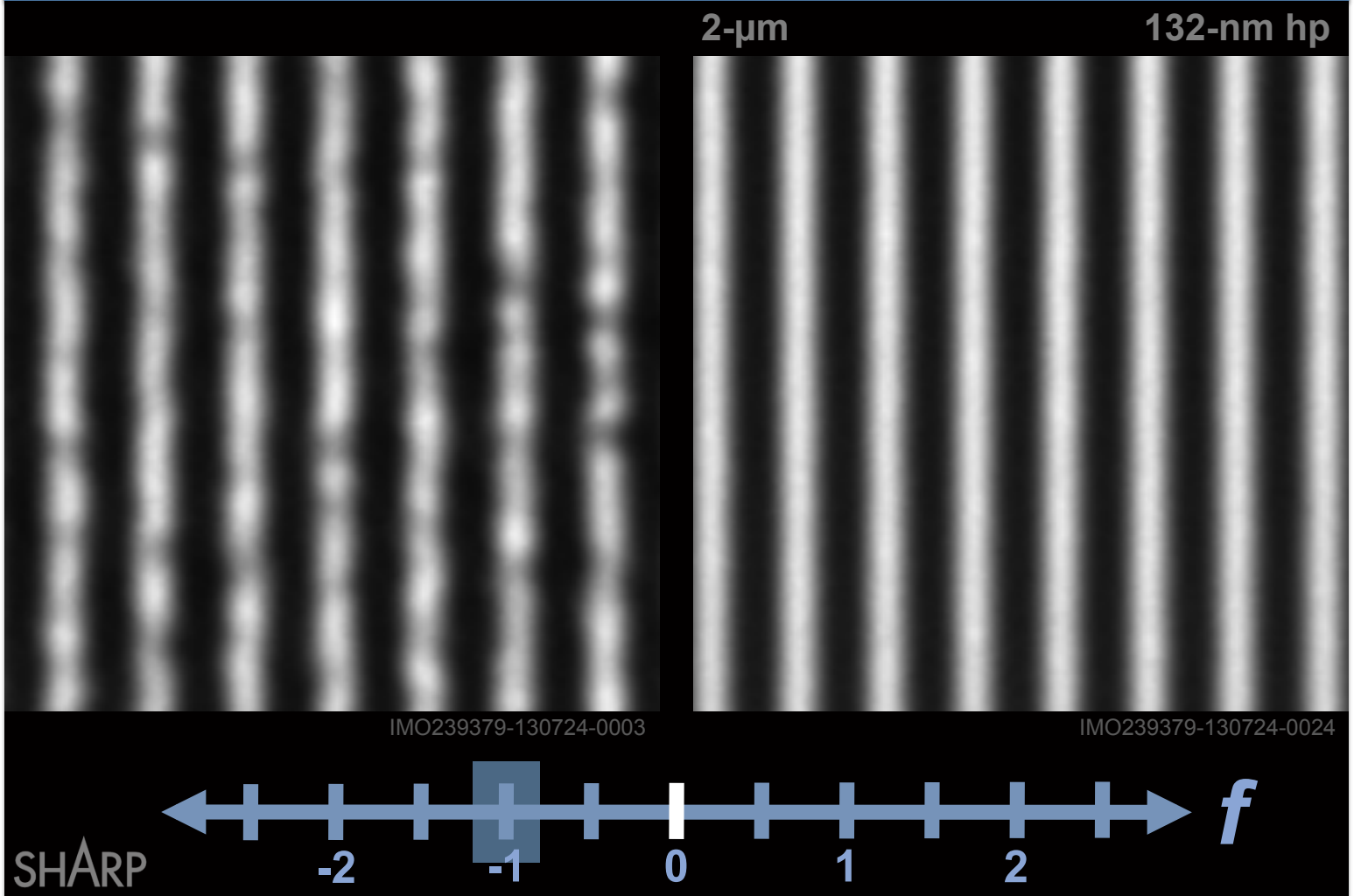

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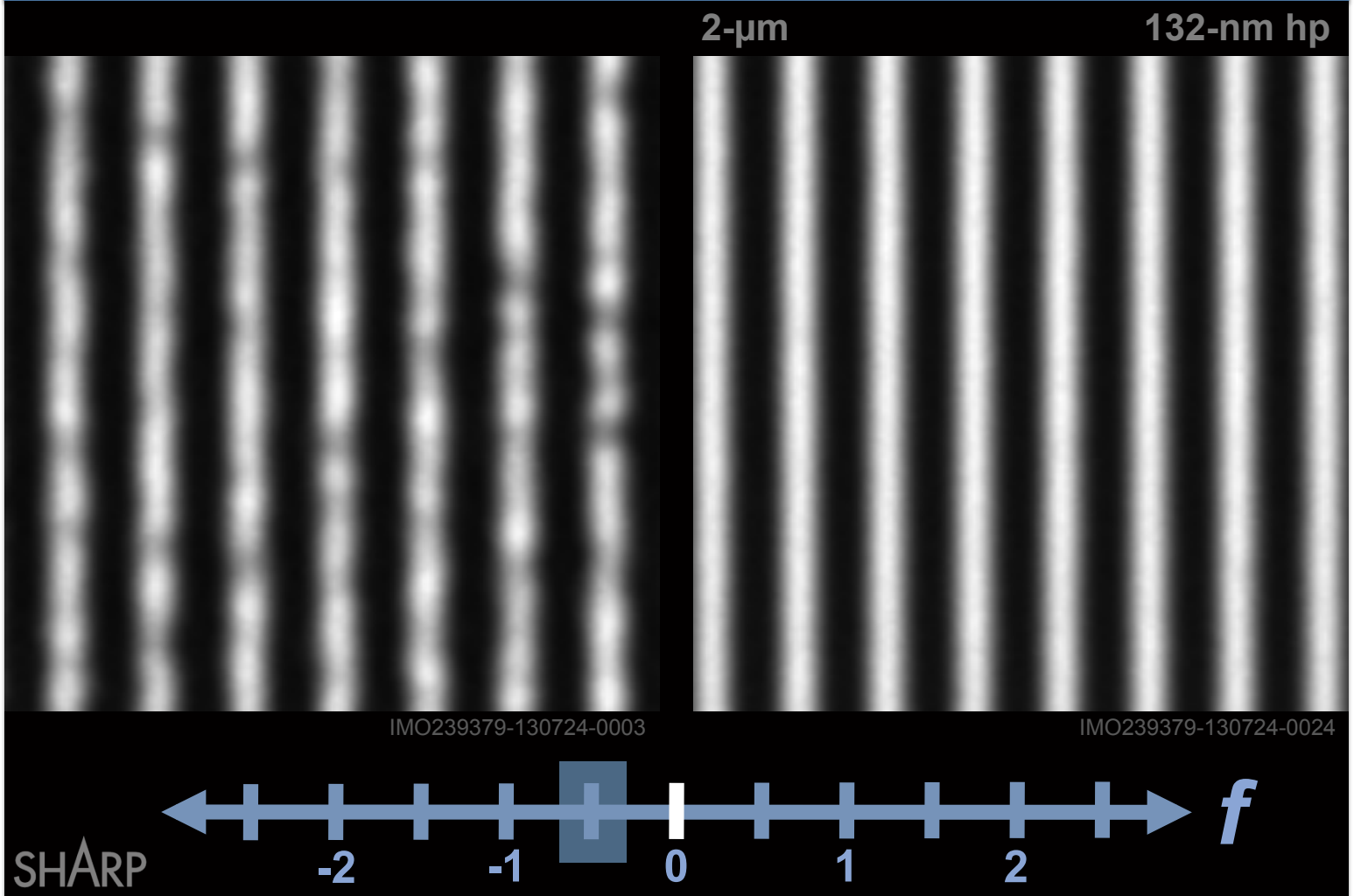

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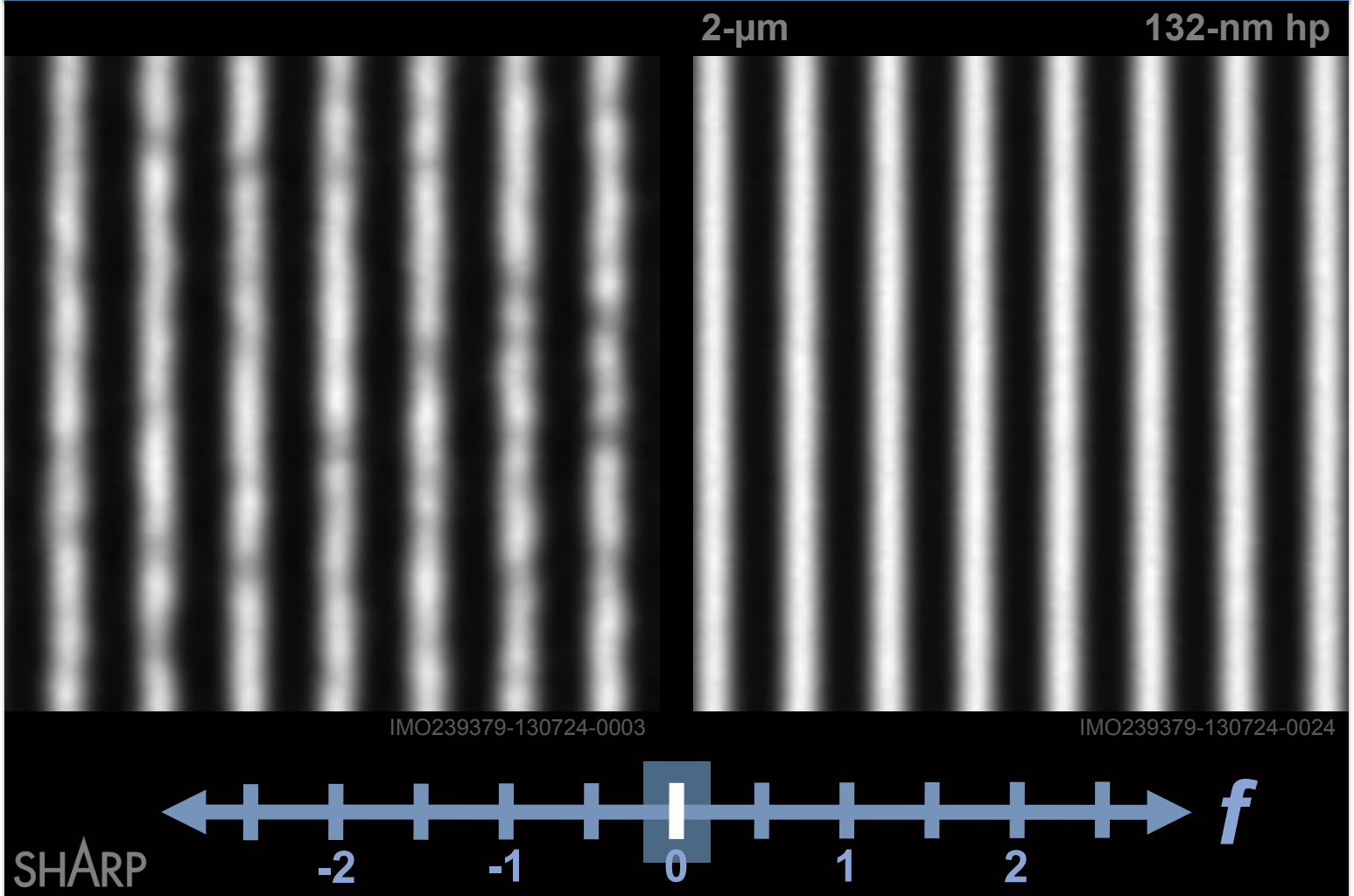

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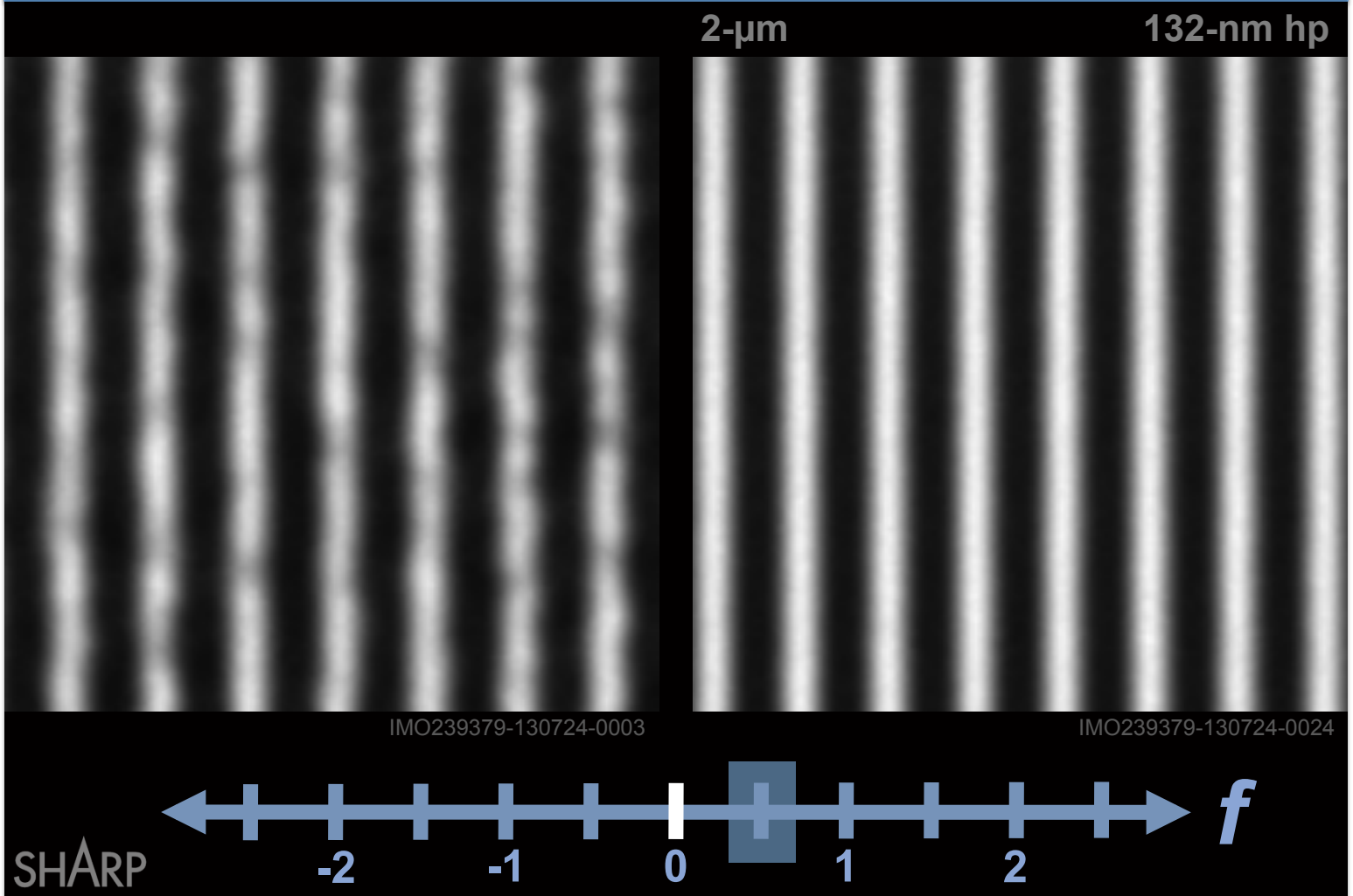

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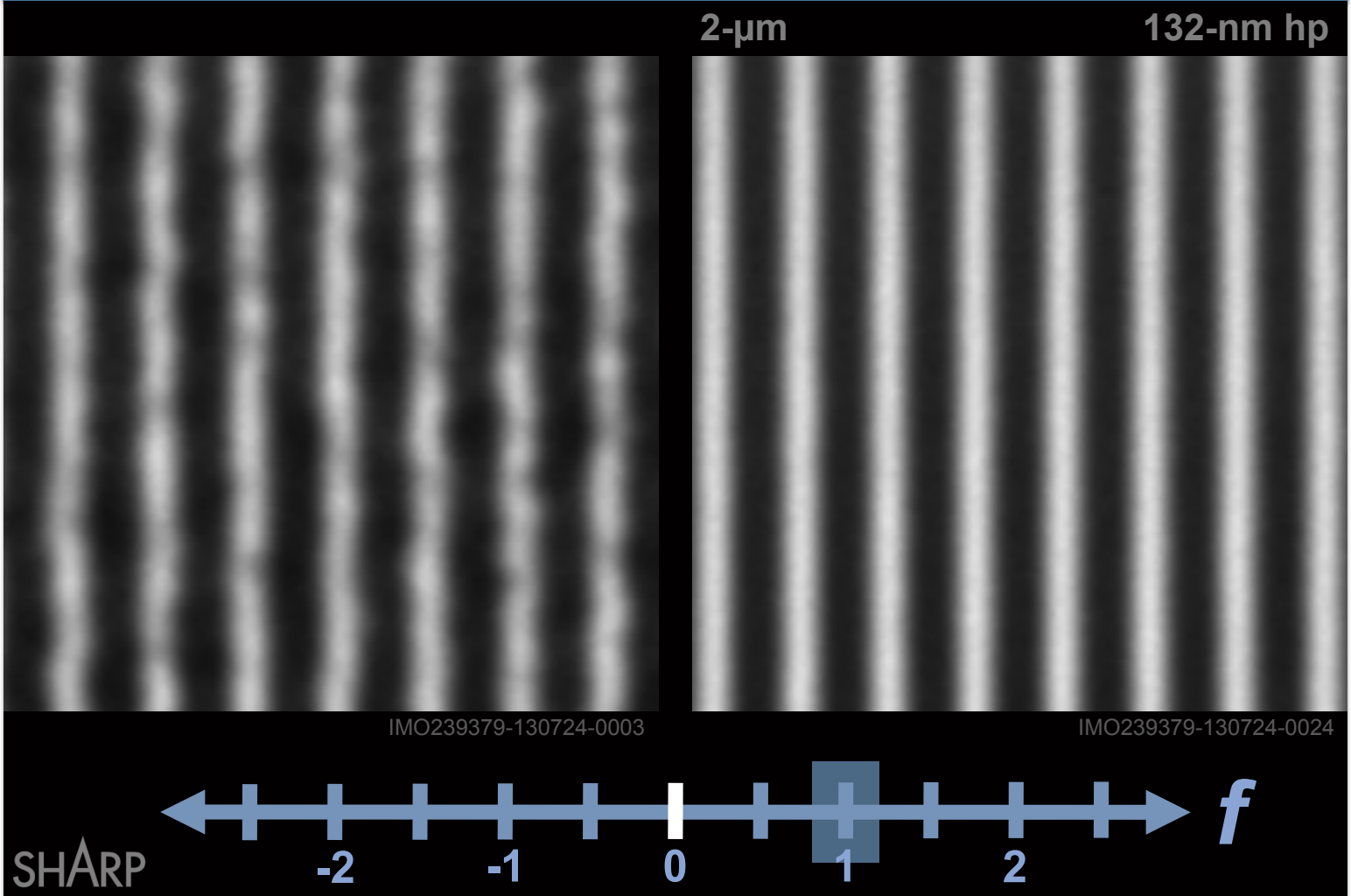

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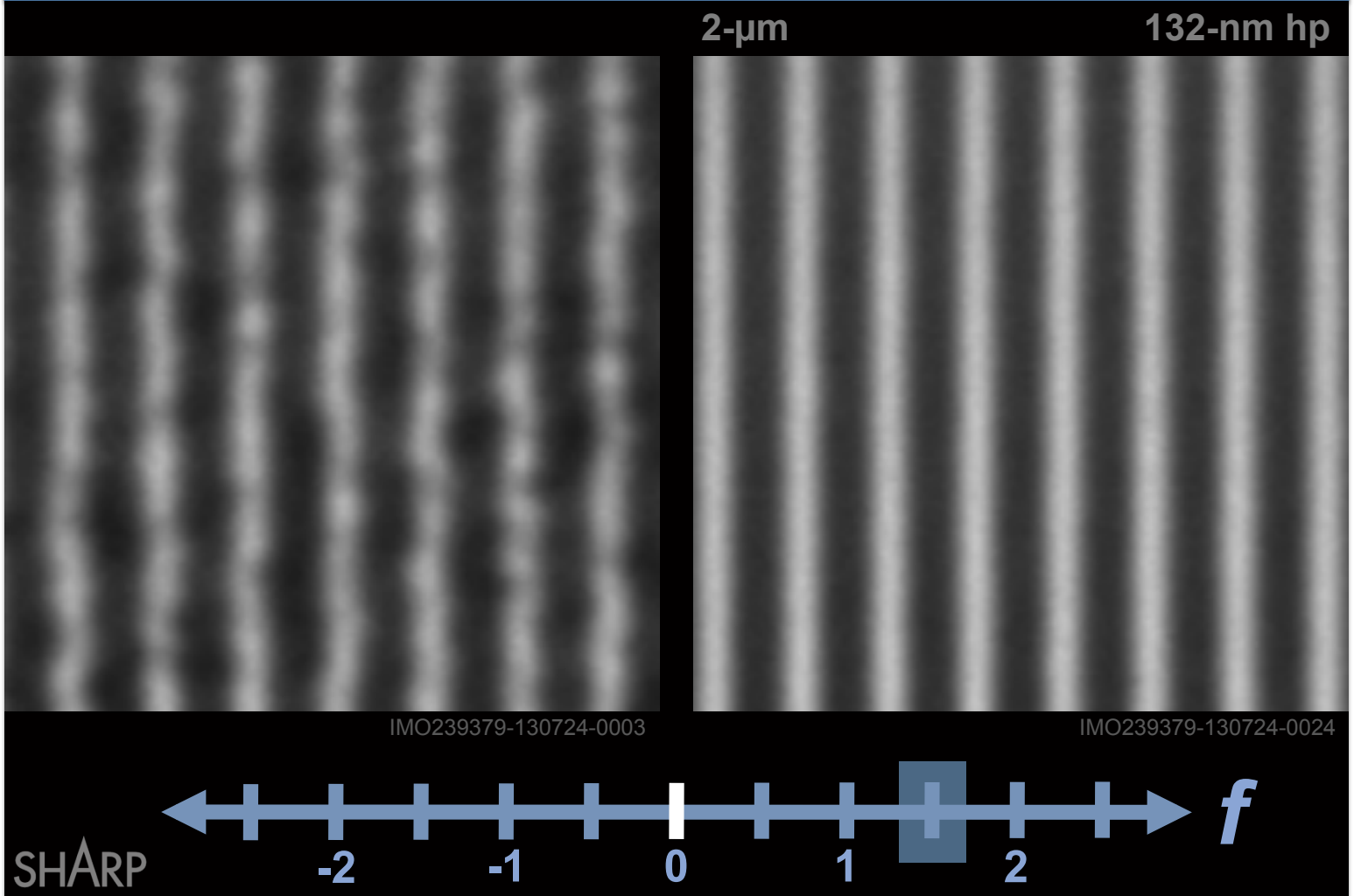

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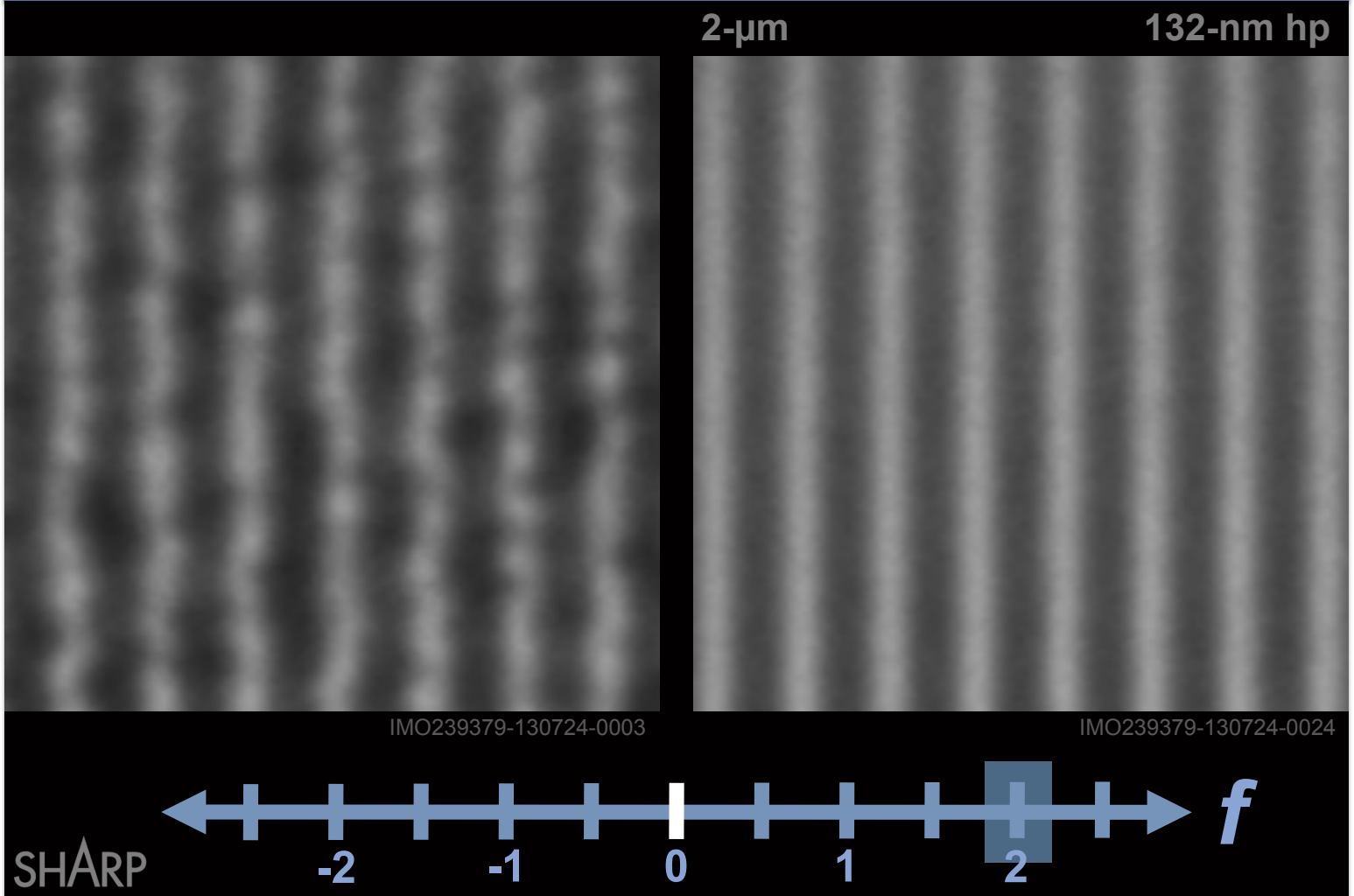

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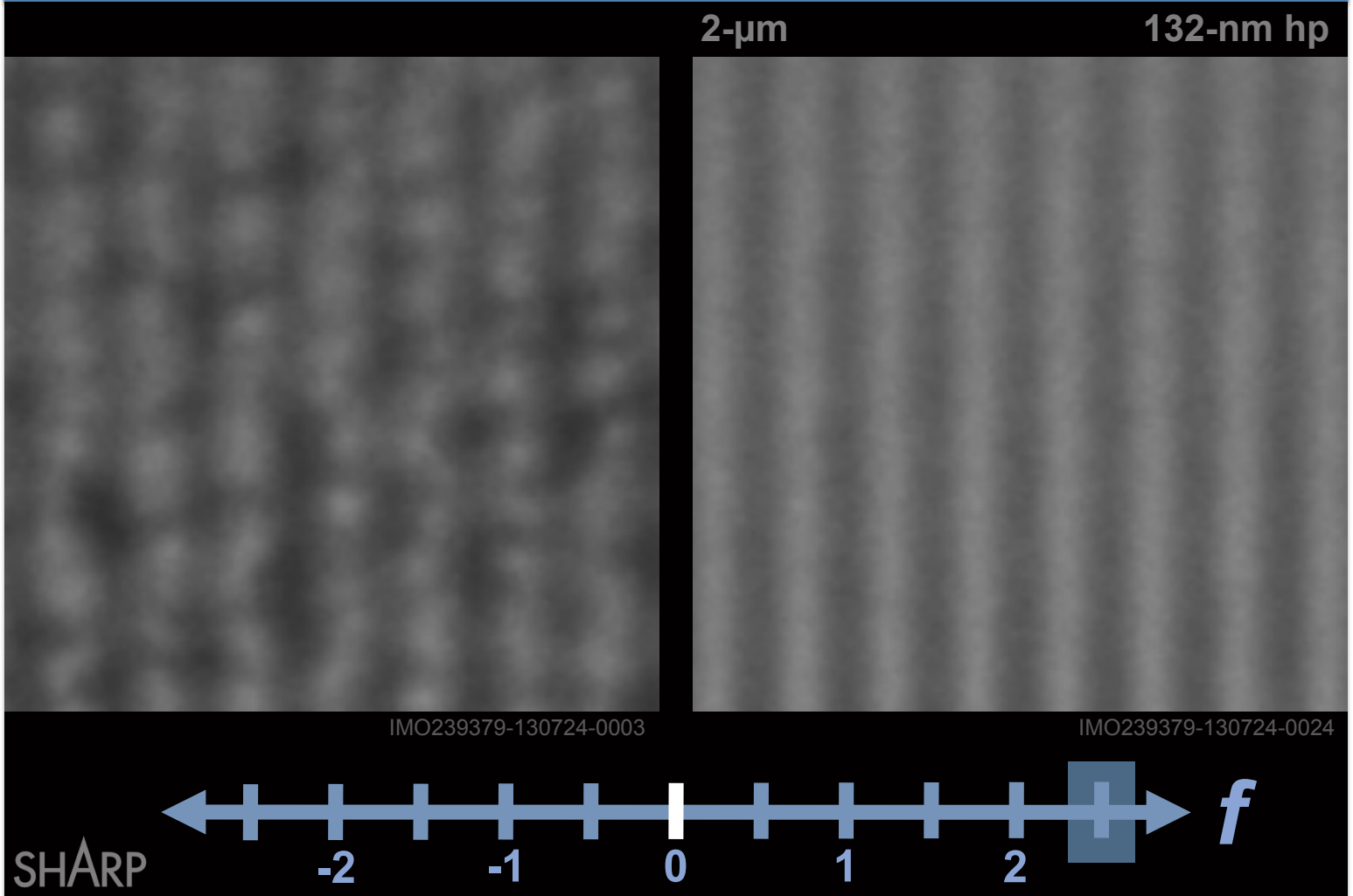

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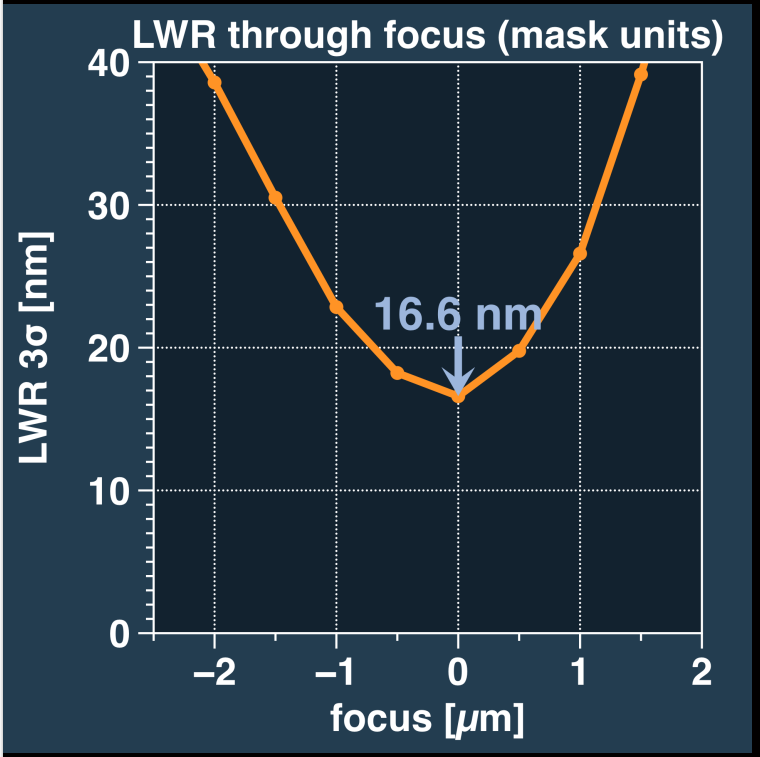

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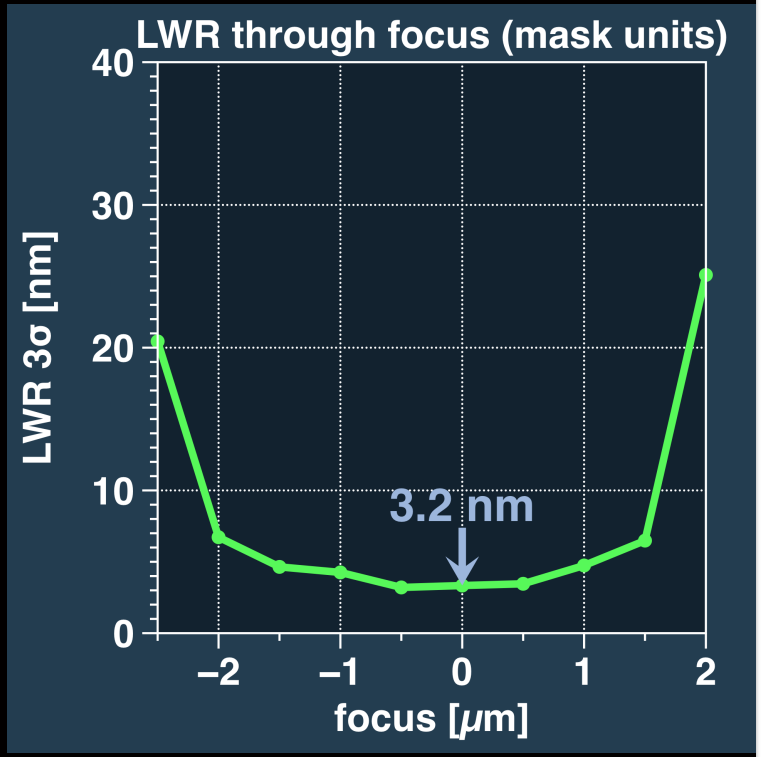

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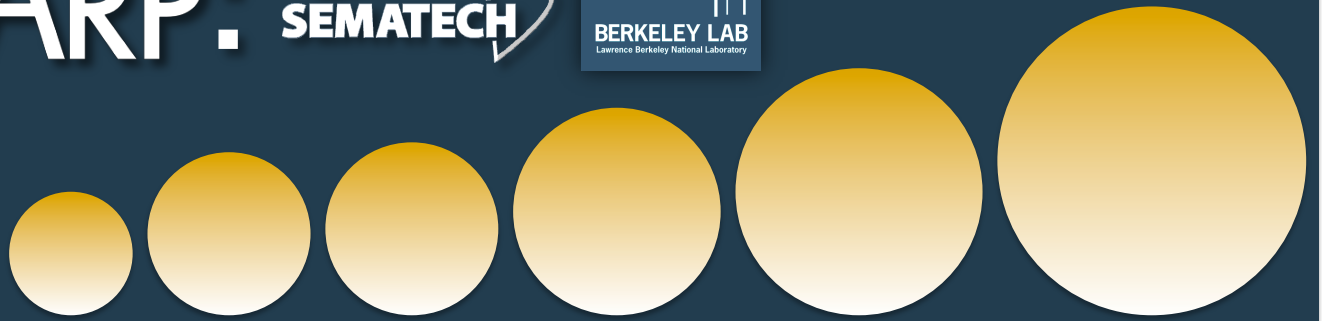
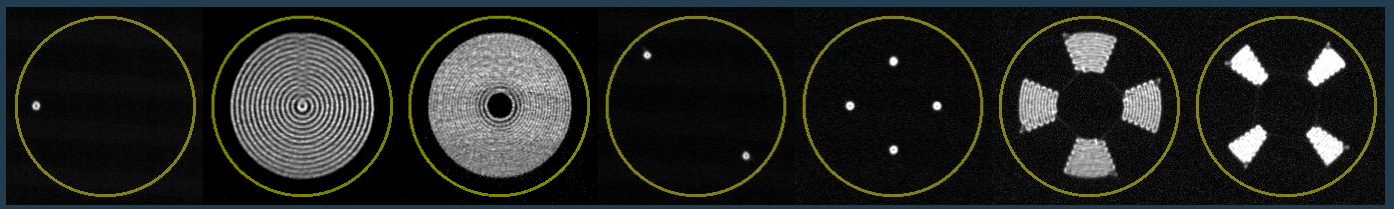


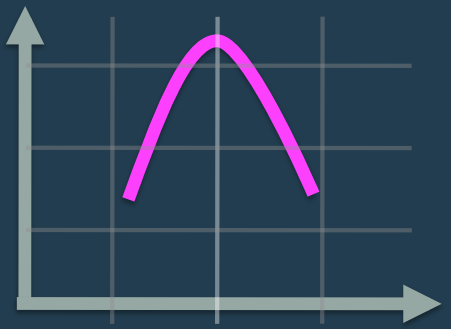
(4x) 0.25 0.33 0.35 0.42 0.50 0.625

σ:



z:

λ:



13.5 nm

***T*:**

~8 pts / h

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